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Volume VI. Number 5

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A SHORT SKETCH OF THE PALEOGEOGRAPHY AND HISTORICAL GEOLOGY OF THE MID-CONTINENT OIL DISTRICT AND ITS IMPORTANCE TO PETROLEUM GEOLOGY

ALEX W. McCOY

PROBLEMS

A statement introductory to this work was made in 1918 at the meeting of the American Association of Petroleum Geologists in a paper entitled "On the migration of petroleum through sedimentary rocks."[1] Unfortunately the title of this paper, which in no way refers to the importance of paleogeography in petroleum geology, was changed in editing.

The evidence presented in this first statement was designed to show from the theoretical standpoint, the impossibility of long distance migration of petroleum from the place of origin. Such reasoning leads to the conclusion that present occurrences of oil are "in situ" phenomena, and that the place of origin of petroliferous deposits is of prime importance in geological exploration of new territory. If it is mechanically difficult and highly improbable for widely disseminated particles of oil to collect in sediments such as the series of Pennsylvanian beds in the Mid-Continent field, it is then necessary that a concentration of the bituminous matter occur with the

[1]McCoy, A. W., On the migration of petroleum through sedimentary rocks, Am. Assoc. Pet. Geol., Bull vol. 2, pp. 168-171, 1918.

original sedimentation and comparatively close to *i. e.* within a few miles of the place of accumulation. The concentrated character of the bituminous substance in the original bed is intricately related to the type and position of the basin in which the formation was deposited. A study of such conditions becomes essentially a study of paleogeography, and the allied subject of sedimentation.

Another statement as to the secondary principal problem of oil geology was made in a paper titled "Notes on the principles of oil accumulation."[2] The essence in this paper was to emphasize the importance of structure in a suitable locality to state briefly the relation of commercial accumulation to structure.

The following paper is an attempt to outline briefly the historical geology of the Mid-Continent field (more especially Oklahoma and Kansas) and to point out some broad relations of historical geology to commercial oil geography. The ideas of the previously mentioned papers, in which only a theoretical argument was advanced, will be assumed in this paper for the sake of investigation. Some instances of geologic conditions will be presented in order to give concrete examples of why these theoretical conclusions have been formulated.

SOURCE OF MATERIAL

The mass of detailed information used to establish the principles as stated was collected at the expense of the Empire Gas and Fuel Company. The data as organized belong to them, but they have kindly given permission to publish the principal conclusions and to use generalized summaries of the assembled facts. The author hereby acknowledges his appreciation of their cooperation and willingness to foster scientific investigation. Acknowledgment is also made to the individual members of the geology department of this company who have assisted materially in the detailed organization of data. Special appreciation is extended Mr. G. E. Moser for the diagrams in this paper.

The author realizes that the presentation of such a range of

[2]McCoy, A. W., Notes on principles of oil accumulation, Jour. Geol., vol. 27, pp. 252-262, 1919.

geologic problems as this paper requires, necessarily affords a large source of probable error. In order to make a connected history a definite stand as to unsettled problems must be made. The facts used for interpretation are emphasized as facts, and the ideas resulting from the most probable imaginative possibilities are stated with the expectation of future change. It is not expected that this paper should be a finished treatise on so broad a problem, but if it serves as an introduction to command attention to worthy research, the paper will have fulfilled its purpose even though later conclusions are materially different from those herewith presented.

Use has been made of all available literature, such as published areal geologic and stratigraphic correlations. Only where the author has made field investigation of particular problems has any material change been made from the accepted correlations and authoritative reports. In many cases it will be impossible to give definite reference to the original source of the information, but credit is given to the many workers who have established the broad geologic facts of the Mid-Continent district.

CORRELATION.

In order to form a connected idea of the succession of Pennsylvanian seas throughout the southwest, it is necessary to accept some form of correlation for the major series of Carboniferous rocks. The correlation table shown in Plate I is presented as a working basis for the geologic history of the district.

The Morrow and Wapanucka formations of Oklahoma have been placed equivalent to the Marble Falls limestones of Texas as previously cited by Girty,[3] Moore,[4] and Mather.[5] The correlations of these formations with the Pottsville of the Appalachian region as lower upper Pottsville has been based on the statement of David White.[6] The Pottsville of the Appalachian

[3]Girty, G. H., The Bend formation and its correlation, Am. Assoc. Pet. Geol., Bull. vol. 3 pp.71-81, 1919.

[4]Moore, R. C., The Bend series of Central Texas, Idem. pp. 217-241.

[5]Mather, K. F., The fauna of the Morrow group, Sci. Lab. Denison Univ., Bull. vol. 18, 1919, pp. 64ff.

[6]White, David, Discussion, Am. Assoc. Pet. Geol., Bull. vol. 3, p. 241, 1919.

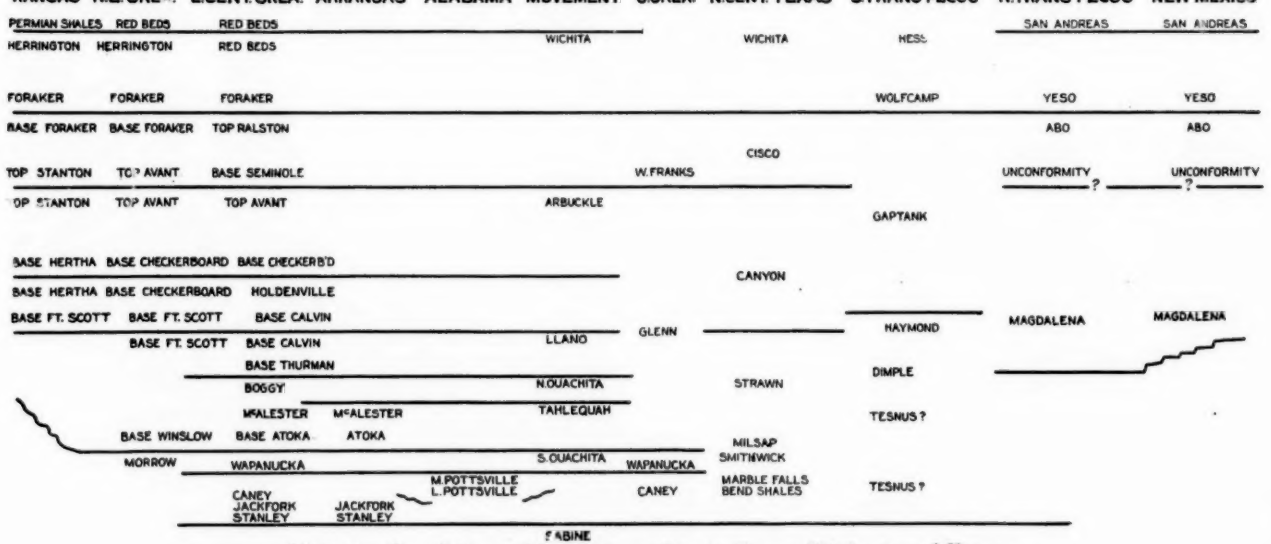

Plate I. Correlation table of formations in Texas, Oklahoma and Kansas.

region shows marked increase in thickness in the lower and middle members toward the south, with the more important limestone members in the upper Pottsville of the central Appalachian region.[7] This more prominent limestone zone following a thick clastic series of sediments has a marked resemblance to the Wapanucka of southern Oklahoma and is tentatively connected with that time.

The Dimple formation of the south trans-Pecos district has been considered by some authors equivalent to the Bend; but after examination of fossil plants in the Tesnus which underlies the Dimple, David White stated in a letter to Sidney Powers that the fossils could not be later than Strawn but that a definite conclusion between Bend and Strawn has not been formed. However, he was inclined to correlate the fossils with Strawn. If such is the case, the Dimple can not be correlated with the Bend. According to Plummer[8] the Millsap formation is entirely lacking in wells drilled south of Gorman and west of Breckenridge. From wells drilled in Cook County, the Strawn has apparently pinched out. It is a fact that the Strawn is very thin, if present at all, at the northwest end of the Llano-Burnet uplift. On account of these conditions, the author favors a correlation of the Tesnus with the Strawn as a southeastward shore phase of a sea approaching from the southwest and not directly connected with the main Strawn basin of east central Texas. The Tesnus shows a gradation landward from west to east as evidenced by marine fossils on the northwest side of the Marathon region and in the southeast portion of this region only poorly preserved plant remains are found.[9] This correlation is entirely tentative but necessarily places the Dimple equivalent to the upper Strawn of Texas and the lower Magdalena of New Mexico.

The correlation for the basis of paleogeographic conditions of the early Pennsylvanian assumes the equivalence of the Marble Falls, Wapanucka and Morrow formations. Conditions

[7]White, David, U. S. Geol. Survey. Prof. Paper 71.
[8]Plummer, F. B., The stratigraphy of Pennsylvanian formations in North Central Texas, Am. Assoc. Pet. Geol., Bull. vol. 3, p. 141, 1919.
[9]Udden, J. A. et al. Review of the geology of Texas, Univ. of Texas, Bull. 44, 3rd ed. p. 49, 1919.

in the Appalachian region, as well as those of the southwest, are doubtful but they are added tentatively in order to present a more complete representation.

The second clearly marked correlation is that of the Fort Scott limestone of Kansas with the Calvin sandstone of eastern Oklahoma.[10] This formation has also been considered the dividing line between the Canyon and the Strawn of north central Texas as suggested by Plummer[11] at the meeting of the American Association of Petroleum Geologists in 1919. According to Beede[12] the lower Canyon is equivalent to part of the Haymond of Texas and part of the Magdalena of New Mexico.

The top of the Kansas City-Lansing division in Kansas, which is formed by the top by the Stanton limestone has been considered to be terminated by the break below the Seminole conglomerate of eastern Oklahoma. This conglomerate[13] has been traced as far north as Okfuskee County and grades into reddish brown sandstones. It lies between the Dewey limestone as mapped by Fath in the Bristow sheet and the Pawhuska limestone mapped in the Cushing district, Plate II.

To the south the main conglomerate has been traced around the north flank of the Arbuckle Mountains within a few miles of Sulphur, Oklahoma, as shown in Plate II. Consequently the Franks conglomerate of the western Arbuckle region must be correlated with the Seminole conglomerate of east central Oklahoma. The conglomerate at Franks, Oklahoma, where the same received its name, can not be traced definitely into any stratigraphic zone, but according to the position of the Wapanucka formation it has probably been erroneously correlated with that particular horizon. The Wapanucka formation changes from 1,200 feet of sandy sediments in Latimer County to a limestone approximately 100 feet thick in eastern

[10]Siebenthal, C. E. Lead and zinc—Mineral resources of Oklahoma, U. S. Geol. Surv., Bull. 340, p. 191, 1908.

[11]Plummer, F. B., Statement.

[12]Beede, J. W., Notes on the geology and oil possibilities of the northern Diablo plateau in Texas, Univ. Texas, Bull. 1852, p. 31, 1921.

[13]The conglomerate termed "Seminole" in this paper is the main horizon in a series of conglomerates, the lower part of which was named the Seminole conglomerate by Taft in the Coalgate folio.

Plate II. Map of portion of Oklahoma showing location of faults and relative position of Seminole conglomerate to Pawhuska and Dewey limestones. The Seminole conglomerate has been traced from the Canadian River southwest along the northwest flank of the Arbuckle Mountains to T. 1S., R. 3 E.

Atoka County. It is illogical to think that this limestone would grade into a very marked conglomerate within just a few miles of where the thickest limestone portion outcrops.

The Cisco of Texas has been placed above this division on account of its difference in lithology from the Canyon. This change in lithology is similar to the change north of the Arbuckle Mountains. The Cisco formation shows a thinning of limestone beds toward the mountains and an increase in the thickness of shales and sandstones with a predominant change to reddish color in the vicinity of Red River.[14] Collections of fossils have been made to aid in this correlation but as yet the identification of these is not complete.

The base of the Permian as determined by Beede[15] is assumed to be correct. This places the base of the Foraker with the overlying marine limestones of Kansas and Oklahoma equivalent to the lower Wichita of central Texas, the Wolfcamp and lower Hess formation of the Glass Mountain district and the Yeso of New Mexico.

Between these principal correlated horizons are several minor points of equivalence. According to the general stratigraphic relation of the Checkerboard limestone to the Lenapah limestone of Oklahoma as described by Ohern[16] the Checkerboard limestone has been tentatively regarded as equivalent to the base of the Kansas City formation or the Hertha limestone. This places the Dewey and Hogshooter limestones equivalent to the Drum and possibly the Winterset of the Kansas sections. The Bluejacket sandstone of eastern Oklahoma which outcrops just west of Pryor, Oklahoma, has been traced south and southeast and mapped by E. A. Trager, W. R. Berger, F. L. Aurin, and D. K. Greger as a sandstone near Warner, Oklahoma, which occurs in the lower portion of the McAlester shale in eastern Oklahoma. A small trilobite horizon, about 70 feet below the Bluejacket sandstone near Pryor was found below the Warner sandstone in several places and this zone was estimated by Aurin to be 150 feet above the top

[14]Udden, J. A. et all, Op. Cit., p. 47.
[15]Beede, J. W., Op. Cit., p. 31.
[16]Ohern, D. W., Statement at meeting of Am. Ass'n. Pet. Geol., 1918.

of the Hartshorne sandstone. According to this information the major portion of the Cherokee shale of Kansas would be equivalent to the McAlester, Savannah, Boggy, Thurman, Stewart, and Sonora formations. The very lowest portion of the Cherokee shale is probably equivalent to the Hartshorne of eastern Oklahoma. It may be true that the Cherokee is not equivalent to the full sections of each of the formations mentioned but only to the portions which extended out to the north, due to oscillation of the seas throughout that time.

The correlation of beds below the Wapanucka, Morrow, and Marble Falls is largely a matter of speculation. If the Stanley shale is of earliest Pennsylvanian, as suggested by Ulrich,[17] since the Caney shale overlies the Jackfork sandstone,[18] the Caney, in part, at least, must be Pennsylvanian and probably equivalent to the lower Bend shales of Texas and possibly parts of the Jackfork of Oklahoma. At least part of this lower Pennsylvanian of Arkansas, Oklahoma, and Texas, should be equivalent to the lower and middle Pottsville of the Appalachian section. Girty[19] is inclined to think that the Caney should be correlated with the Moorefield of Arkansas which is Mississippian; and since it overlaps the Jackfork sandstone, the conclusion that the Stanley is upper Mississippian and that the sedimentation of the Stanley is peculiar and excessive seems to involve the fewest inconsistencies although it is by no means entirely satisfactory. Schuchert[20] is inclined to agree with Girty. David White[21] regards the Stanley as either very late Mississippian (possibly upper Chester) or Pennsylvanian of an earlier date than he is familiar with in the Appalachian trough. The author favors a correlation of the Stanley with either the earliest Pennsylvanian or Mississippian younger than the Pitkin limestone of

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[17]Ulrich, E. O., Cited by Honess, Am. Jour. Sci., 5th ser., vol. 1, p. 78, 1921.

[18]Girty, G. H., Relation of some Carboniferous faunas, Wash. Acad. Sci., Proc., vol. 7, pp. 11-12, 1905.

[19]Girty, G. H., Fauna of the Caney shale of Oklahoma, U. S. Geol. Surv. Bull. 377, pp. 8-10, 1909.

[20]Schuchert, Chas., Private correspondence.

[21]White, David, Cited by Honess, Am. Jour. Sci., 5th ser., vol. 1, p. 76, 1921.

Oklahoma, since the upper Mississippian of northeast Oklahoma and Arkansas shows a marked increase in lime content at the southwest extremity of its exposure. This condition, which can be traced farther south by well logs, is rather contradictory to the possibility that their equivalents in the Ouachita region could be such a thick series of clastic sediments in relatively so short a distance. The exact correlation of these formations is comparatively unimportant from the standpoint of this paper, except as a preparation for a sequence of seas up to the Marble Falls, Wapanucka, and Morrow time.

PALEOGEOGRAPHY.

The seas of Pennsylvanian time are marked during the early stages as narrow, muddy basins of an oscillatory nature. During the middle and late Pennsylvanian, widespread limestone conditions became more prominent.

The positive elements on the North American continent at the beginning of Pennsylvanian time were (as shown in the paleogeographic map, Plate III, after Schuchert), about the same as those controlling the great majority of former Paleozoic seas. At the close of Permian time, marine conditions had ceased to exist in the central and eastern portions of the United States. Consequently, the greatest physiographic changes should be expected during Pennsylvanian and Permian times. In the series of paleogeographic maps which are here presented, the author has postulated the particular time of arrival of these physiographic changes from the meager evidence available in unconformities and gradations in the sediments.

According to Plate III the thickest zone of pre-Pennsylvanian Paleozoics lies along the dashed line from southern New Mexico to the southeastern corner of Oklahoma and from north central Alabama northeast along the Appalachian trough. Between the southeastern corner of Oklahoma and the south-central part of Alabama nothing is known of the thickness of the early Paleozoics on account of overlap by younger strata. It is reasonable, however, to assume that these areas are connected by a thick path of early Paleozoic

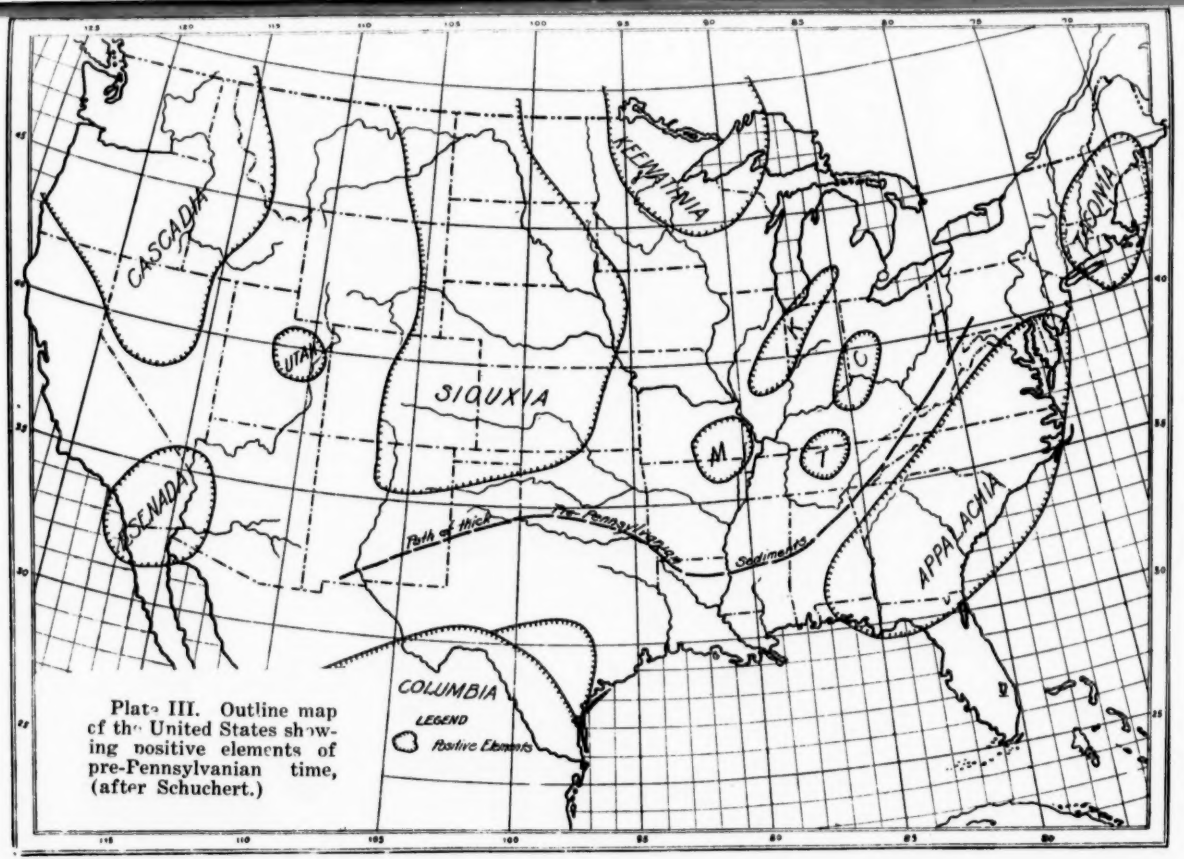


Plate III. Outline map of the United States showing positive elements of pre-Pennsylvanian time, (after Schuchert.)

sediments. Since the Appalachian trough has such a marked alignment southwest at its southern known extremity, it is most likely that this connection extended southwest through Alabama crossing south central Mississippi and east central Louisiana, thence northwest in a curved direction to the southeast corner of Oklahoma. Any readjustment of isostatic conditions should take place along this path of early Paleozoics extending down the Appalachian trough across Mississippi, Louisiana, southern Oklahoma, into New Mexico.

What thickness of sediments can be deposited in an epicontinental trough before readjustment takes place, is a problem of isostasy. This brings up questions of the failing nature of the earth's surface concerning which there are differences of opinion among geologists and geodesists. It is only important in this paper to accept the general conditions as evidenced by the many readjustments which have taken place in zones of thickest sediments, and to account for rapid accumulation of sediments from recent physiographic highs where such could have logically occurred.

In very late Mississippian or earliest Pennsylvanian times, there was formed a thick series of clastic sediments, the Stanley-Jackfork in southeastern Oklahoma and southwestern Arkansas. These sediments most certainly were derived from some prominent physiographic feature comparatively close to the position of sedimentation. This physiographic feature probably was the result of isostatic adjustment, as no evidence of sedimentation previous to that time indicates a prominent high land mass near the southeast corner of Oklahoma. This land mass could not have been west or north of the Jackfork and Stanley outcrops as this area was repeatedly covered by Pennsylvanian seas. The only direction in which it could have occurred along the axis of thickest Paleozoics would be east and possibly southeast. South and east of the Stanley-Jackfork outcrops the Sabine uplift of the present time is the only physiographic feature which is suggestive of an old land mass. The possibility that the Sabine uplift is a buried

zone of hills, has been well discussed by Powers.[22] The author had arrived at the same conclusion before the publication of Powers' article; but wishes to accept Powers' idea of this possibility and to place the main Sabine uplift in pre-Stanley time.

Such an uplift as just outlined would materially affect the marine Gulf connection with the Appalachian trough, and would possibly leave a low area intermittently connected with marine conditions throughout southeastern Oklahoma and southern Arkansas as shown in Plate IV*A*. A high land mass in the position of the Sabine uplift could rapidly furnish the thick sediments of the Jackfork and Stanley formations. Folds resulting from stresses accumulated in this basin of sediments would probably run northwest-southeast, which would facilitate subsequent deposition of maximum debris near the southeast corner of Oklahoma.

From such a geographic condition, the first Pennsylvanian seas advanced upon the area now known as southern and eastern United States. The lower Bend shales were probably accumulated in a narrow neck of the sea which was advancing either from the southwest, north of the positive element, Columbia, or east of this and southwest of the newly named positive element, Sabine. Paige and Girty[23] and Moore[24] have shown that the lower Bend shales pinch out between the region of San Saba and Marble Falls, Texas. This is inconclusive as to whether the connection of the lower Bend basin was to the southwest or to the east and south as shown in Plate IV*A*. At any rate, this basin was probably connected to the northeast with part of the Caney basin and perhaps from there east across the Arkansas trough to the Pottsville of Alabama. The Pottsville of Alabama may have been connected directly with the Gulf as indicated by Plate IV*A*, but

[22]Powers, Sidney, The Sabine uplift, Louisiana, Am. Assoc. Pet. Geol., Bull. vol. 4, pp. 117-136, 1920; Miser, H. D., Llanoria, the Paleozoic land area in Louisiana and eastern Texas, Am. Jour. Sci., (5), vol. 3, pp. 61-89, 1921.

[23]Paige, Sidney and Girty, G. H., U. S. Geol. Surv. Geol. Atlas, Llano-Burnet folio (No. 183), 1911.

[24]Moore, R. C., Op. cit, p. 219.

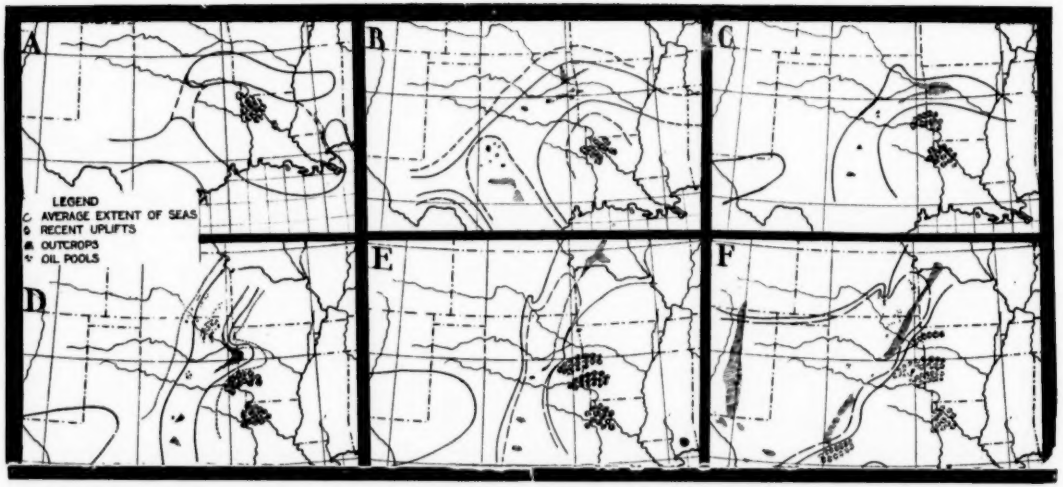
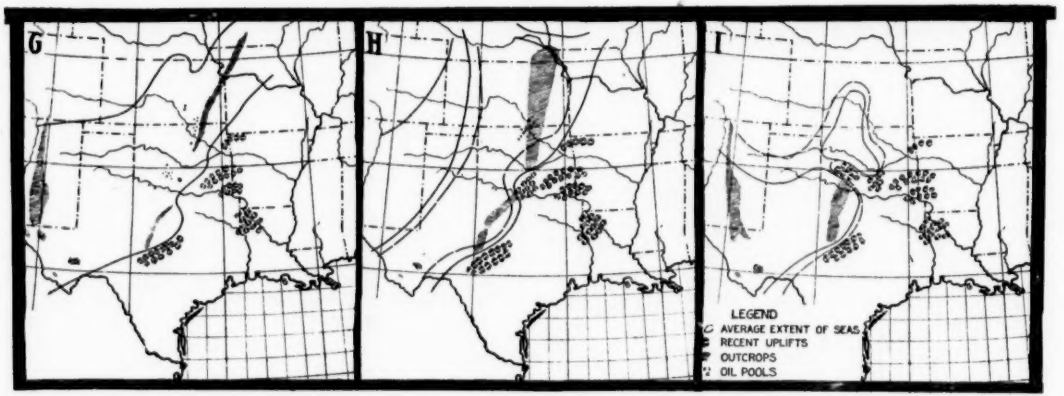


Plate IV. Paleogeographic maps showing average extent of seas, recent uplifts, outcrops, and oil pools in sediments of the period. *A* Geography during transition from Mississippian to Pennsylvanian; *B*, Marble

Falls-Wapanucka-Morrow time; *C*, Millsap-Atoka Hartshorne time; *D*, Tesnus (?)-Millsap (or early Strawn)-McAlester-lower Cherokee time; *E*, Lower Magdalena-Haymond-lower Canyon-Henryetta time; *G*, Magdalena(?)-lower Gaptank-upper Canyon-Kansas City toend of Stanton time; *H*, Gaptank and some Permian-Cisco and some Permian-Douglas to end of Herington time; *I*, San Andreas-Hess-Wichita-Permian "Red Beds" of Oklahoma and Kansas time.



this connection seems rather improbable and the author favors a westward connection at the southern end of the Appalachian region through Arkansas, into Oklahoma and southwest. The Appalachian Pottsville shows intermittent marine connections, but by the time the Arkansas trough is eliminated, the southern Appalachian region is practically cut off from marine seas.

Plate IV*B* shows the possible geographic arrangement of the Marble Falls, Wapanucka, and Morrow basin. The connection to this sea was either to the southwest or to the southeast as shown. The author favors a connection to the southeast as there is no indication of landward gradation of sediments in the Marble Falls to the southeast and accurate correlation between the Marble Falls and Tesnus or Dimple of the Glass Mountain district is lacking. The gradation as shown by well logs across north central Texas on the Marble Falls limestone is in a northeast direction. Consequently, the author has enclosed an area by dashed lines within the Marble Falls basin which seems most probably the central portion of this particular sea.

The Morrow formation shows marked landward gradation to the north in Oklahoma and a thinning of the lime members eastward into Arkansas. The Wapanucka formation shows very marked gradation to clastic sediments toward the east and also a sandy phase toward the west according to a tentative correlation of the Wapanucka in the Glenn formation by Schuchert. These facts are the bases for drawing the limits of the Morrow-Wapanucka portion of the sea in Oklahoma and Arkansas, together with the fact that the outcrops are absent elsewhere.

The principal oil deposits of this particular time in the Pennsylvanian are the fields of north central Texas, which produce oil from the "black lime." These pools trend a little north of west and south of east throughout Stephens, Eastland, and northern Comanche counties. This alignment is in the direction of more equal character in the Bend sediments and is normal to the direction of gradation. It is also about in line with the direction of the main part of the basin as out-

lined by the inner dashed line in Plate IV*B*. There are possibly some oil pools in the Morrow formation of Oklahoma either in Tulsa, Okmulgee, or southeastern Creek counties, but a definite correlation between the Morrow and upper Mississippian can not be made at this time; consequently, the Oklahoma oil pools have been omitted on the map.

Following Wapanucka and Morrow times in Oklahoma, there was a decided readjustment in the source of sediments although not an important change in the position of the sea (Plate IV*C*). A great series of clastic sediments, namely, the Atoka, was deposited in southeastern Oklahoma and western Arkansas, but extending farther north than the Jackfork and Stanley. It is here that the author postulates a rise in the southern Ouachita Mountains across McCurtain County and eastward into Arkansas. This elevation of land could result from accumulated stresses acting in the area where the Jackfork and Stanley formations overlie the thick belt of previous Paleozoic sediments.

The Stanley and Jackfork formations, if the same were derived from the area of "Sabine," would overlap the path of thickest pre-Stanley sediments on the northwest flank of the Sabine uplift. Consequently, isostatic adjustment, if due to overloading of sedimentary basins, should take place next in the area northwest of the Sabine uplift, and should not necessarily be connected with that folding. The folds, if beginning with wrinkling in the Stanley and Jackfork, would be expected to form arcuate folds about Sabine as a center. In this connection, it is worthy to note the arcuate nature of the folds in the southern Ouachita Mountains. From the southern central part of McCurtain County, Oklahoma, the folds run in a curving northeastward direction with the concave side to the southeast, and after crossing the Oklahoma-Arkansas line, these folds straighten out to an east-west direction. A categorical statement concerning similar mountain range distribution is given by Hobbs.[25]

The first movement in the Ouachita region is considered to

[25]Hobbs, W. H., Mechanics of formation of arcuate mountains, Jour. Geol., vol. 22, p. 77, 1914.

have affected the area throughout McCurtain County, Oklahoma, and east into Arkansas. North and west of this folded area is a synclinal belt of low dips which separates the northern and southern Ouachita zones of steep folding. The northern folding is interpreted as having occurred at a later date than that south of the synclinal trough, but as having resulted from similar stresses. The type of folds are similar, and the later folds form outer concentric belts which agree with the interpretation presented by Hobbs. The times of folding also check the distribution and change in sedimentation.

The basin following Morrow-Wapanucka time across Texas is probably evidenced by the sediments of the Millsap formation. On account of the pinching out of the Millsap to the west as shown by Plummer[26] and to the fact that the sediments increase markedly in thickness in an east and northeast direction, the author is inclined to connect this sea southeast from the central Texas region similar to the main connection of the Bend basin. At the same time, there was probably an arm of the Pacific sea crossing the trans-Pecos region. The Tesnus at least shows marine gradation to the west and may be equivalent to this particular group of sediments. The conditions are geographically shown in Plate IV*D*. The sediments of this particular time were rapidly accumulated in a comparatively narrow basin which probably sank about as fast as the sediments were deposited and little opportunity was afforded for the formation of bituminous shales. Consequently, this group of sediments is practically barren of oil in Oklahoma and Arkansas although there are possible pools in central Texas, as this area was further removed from the source of thick sedimentation and more likely to receive the deposition of bituminous formations.

Following Atoka time, the Pennsylvanian sea advanced northward across Tulsa, eastern Osage, Washington, and Nowata counties, Oklahoma, into southeastern Kansas (Plate IV*D*). This is evidenced by the data presented in the discussion of correlation. Such a shifting is the natural result, as the Arkansas trough was being filled with sediment and the low district between the Ozark land of Missouri and

[26]Plummer, F. B., Op. cit.

Siouxia of Kansas would naturally furnish a trough for the advancement of a new sea. This trough, as shown by Berger,[27] contains sands on the Mississippian floor which are suggestive of river channel deposits. Such evidence harmonizes with the interpretation that the sea advanced northward into this district. The water probably filled first the main river channels and extended from these outward in all directions. Such rivers most likely formed the main lines of drainage for all of the territory north of Kansas, Missouri, Nebraska, and Iowa, previous to Cherokee times.

As the sea advanced in this northern extension, comparatively thin sediments were formed consisting of black shales and sands. The sands were deposited in belts parallel to the outline of the basin. To the south and east thicker clastic sediments with occasional coal members were deposited throughout Atoka, Pittsburgh, Haskell, Latimer, and Le Flore counties, Oklahoma. In such a series of sediments, bituminous shales are hardly to be expected on account of the rapidity with which the material is laid down when the area was covered by a marine sea. In the Glenn formation of southern Oklahoma, a series of bituminous shales and asphaltic sands were deposited at about this time. Such a correlation which has been made by Goldston[28], leads, of course, to the probability that the oil fields of Carter County, Oklahoma, belong to such a period of Pennsylvanian sedimentation. At least, it is more probable that bituminous shales were formed at this particular time throughout Jefferson, Love, Carter, Murray, Garvin, and Pontotoc counties than at any other time in the Pennsylvanian. The source of rapid accumulative sediments is farther removed and the part of the basin which crossed these counties is probably more quiet than at any later time. It is also probable that the petroliferous Strawn sands of southwestern Palo Pinto County, Texas, were deposited at about the same date. Plate IV *D* illustrates a tentative idea of the arrangement of the basin showing the oil

[27]Berger, W. R., The extent and interpretation of the Hogshooter gas field, Am. Assoc. Pet. Geol., Bull. vol. 3, pp. 212-6, 1919.

[28]Goldston, W. L., Jr., Differentiation and structure in the Glenn formation, Oklahoma. Presented at the meeting of the Am. Assoc. Pet. Geol., 1921.

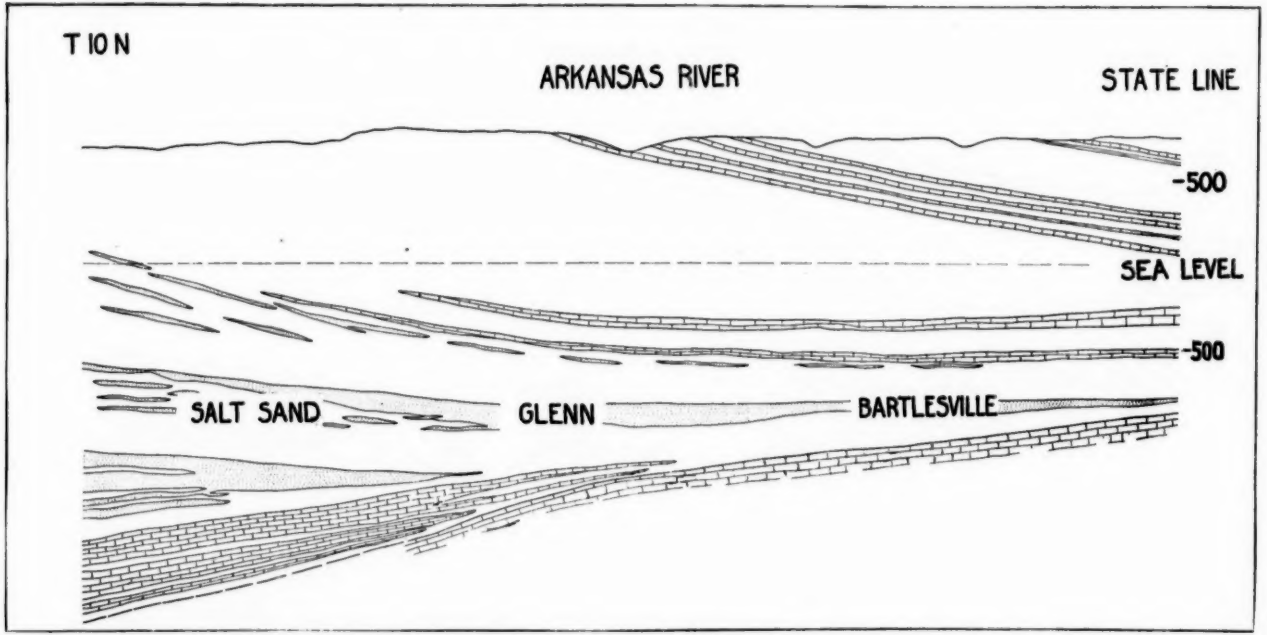


Plate V. Cross-section in north-south direction from Kansas to T. 10 N., Oklahoma, along R. 11-12 E., showing gradation in character and thickness of sediments compiled from 157 well logs.

pools, outcrops, and probable limits of the sea.

Plates V, VI, and VII show by cross-section the nature of the Pennsylvanian sediments in northeast Oklahoma and southeast Kansas, along lines respectively north and south, and east and west. The data on the sediments below the Fort Scott limestone has been used to help in the outline of the basin in this district. It is interesting to note that the productive portion of the oil sand follows the general alignment of the basin, although the sands themselves may extend out from the region of productivity. Especially is this true in the northeastern extension of the Bartlesville sand from the Nowata pool and the southeastern extension of the Salt sand in the Okmulgee-Muskogee region. Pools producing from near the top of the Mississippi lime which probably derive their oil from the Cherokee shale also take the general alignment of the Cherokee basin, as the Blackwell, Oklahoma, and Fox-Bush, Sallyards, Young, and Teeter pools, Kansas. Recently a trend of low Cherokee sand has been shown in western Osage in the vicinity of Burbank, Oklahoma, and at Grenola and Howard, Elk County, Kansas, which extends in a northeast-southwest direction, with alignment parallel to the shore of the basin. Berger[29] has shown that the relative amount of sediments filled in this northeastern Oklahoma-southeastern Kansas trough up to Fort Scott time.

Plate IV*E* illustrates a somewhat later time than shown in Plate IV*D* with some additional physiographic features. The northern portion of the Ouachita Mountains, the folding along the Tahlequah axis, and possibly part of the Boston Mountains of northwestern Arkansas, are thought to have occurred during the advance of the Cherokee sea. Evidence for the Tahlequah movement is obtained from field observations in the area just west of Wagoner, south to Warner and Webber Falls, Oklahoma. The lower Cherokee beds are tilted and faulted with the upper Mississippian, while the upper beds of the Cherokee show practically no disturbance. Lower sandstones in the McAlester formation, south of Muskogee,

[29]Berger, W. R.. The relation of the Fort Scott formation to the Boone chert in southeastern Kansas and northeastern Oklahoma, Jour. Geol., vol. 26, pp. 618-21, 1918.

are tilted up in the region just west of Webber Falls at an angle of 8 to 10 degrees. This abrupt change is accounted for by "Tahlequah" folding and faulting and may be traced for some distance northeast and southwest. In going southwest, however, the Boggy and Savannah formations are laid down over this series of folds with apparent unconformity.

The evidence for the north Ouachita movement, which was subsequent to the Tahlequah, is shown by the sedimentation of the Thurman sandstone, and by the change in strike of all subsequent formations in eastern Oklahoma. A description of the Thurman sandstone in the Coalgate folio illustrates the marked change in character of the sediments at this particular time. It also shows that the conglomeratic character of the Thurman sandstone, as well as the sandy nature of the later sediments, was very noteworthy in the eastern Coalgate district. The reason for folding as shown in Plate IV*E* may be taken as due to the accumulated stresses formed by the thick sediments of the Atoka, Hartshorne, McAlester, Savannah, and Boggy formations along the south flank of the Arkansas trough. This folding was probably so developed that it may now appear as merely a continuation of the first Ouachita movement.

Attention is now called to the fact that due to the northeast-southwest arrangement of folds in southeastern Oklahoma, the great portion of the drainage would be turned southwest into Texas. This may account for the more sandy portion of the Strawn formation, although sandy sediments should have been collecting in central Texas intermittently after the first Ouachita movement. At the same time, a sea was in evidence in southern New Mexico, and the trans Pecos region of Texas. It seems doubtful on account of the thinning of the Strawn to the west if this sea was actually connected with the Strawn basin of Texas.

Beginning with Plate IV*F* which illustrates conditions in Henryetta (lower Marmaton), Canyon, and Magdalena time, a decided change has come over Pennsylvanian sedimentation in Oklahoma, Kansas, and Texas. This change is marked by the prominence of limestones throughout the greater portion

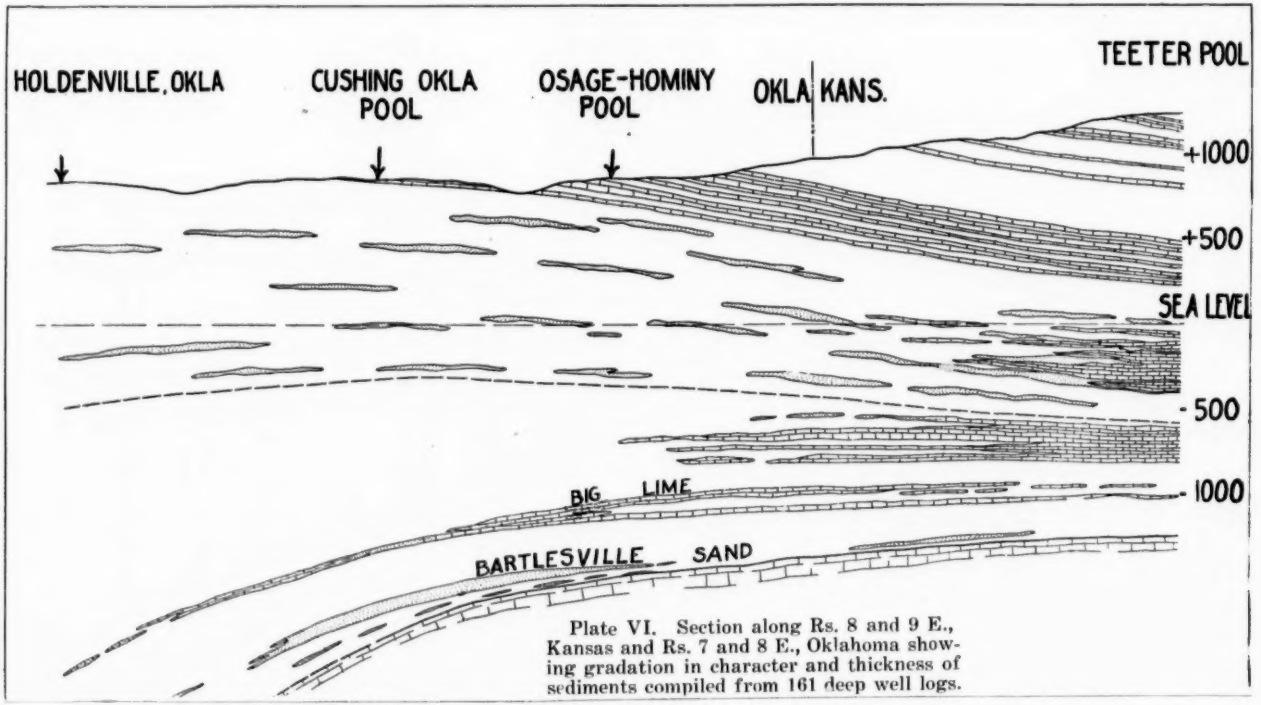


Plate VI. Section along Rs. 8 and 9 E., Kansas and Rs. 7 and 8 E., Oklahoma showing gradation in character and thickness of sediments compiled from 161 deep well logs.

of the southwestern interior, and this series of limestones is the first prominent limestone zone deposited in any of the Pennsylvanian seas since Marble Falls, Morrow, and Wapanucka times. The marked difference in the character of the sediments is credited to the widespread invasion of a limestone-forming sea from the southwest, connecting with the previous narrow, muddy trough of the Cherokee and Strawn basins.

From the conglomeratic and sandy nature of the Canyon sediments at their southwest extremity, some movement in the Llano-Burnet uplift has been postulated at this time. The faults and the folds of this uplift generally run northeast and southwest. Granitic "highs" evidenced in wells drilled near Waco, Texas, as well as the position of the Edwards Plateau, suggest a rather extensive line of hills in both a northeast and southwest direction from the present Llano region. Such a movement might result from stresses accumulated by the thickness of the Strawn and lower sediments. There is no evidence to show that the Strawn sediments were derived from the Llano-Burnet uplift.

The Henryetta group of formations shows a landward gradation from marine conditions in southeastern Kansas, both to the north and to the south as evidenced by the pinching out of limestones, and the increase of sands and shaley sediments with coal. The same group of formations are shown to pinch out in lapping around the buried granite hills of Kansas.

The oil fields of the Mid-Continent, where production is probably coming in or near the Henryetta sediments, are also shown on Plate IV *F*. The arrangement of these fields bears out the general line of the basin, especially from Augusta to El Dorado, around to Franklin, Miami, Linn counties, Kansas, and southwest through Chautauqua county, Kansas, Washington, Osage, and Creek counties, Oklahoma, and probably some of the deeper horizons in Stephens and Cotton counties, Oklahoma.

Plate IV *G* illustrates a continuation of limestone conditions from the base of the Kansas City to the top of the Stanton in Kansas, probably equivalent to the upper Canyon

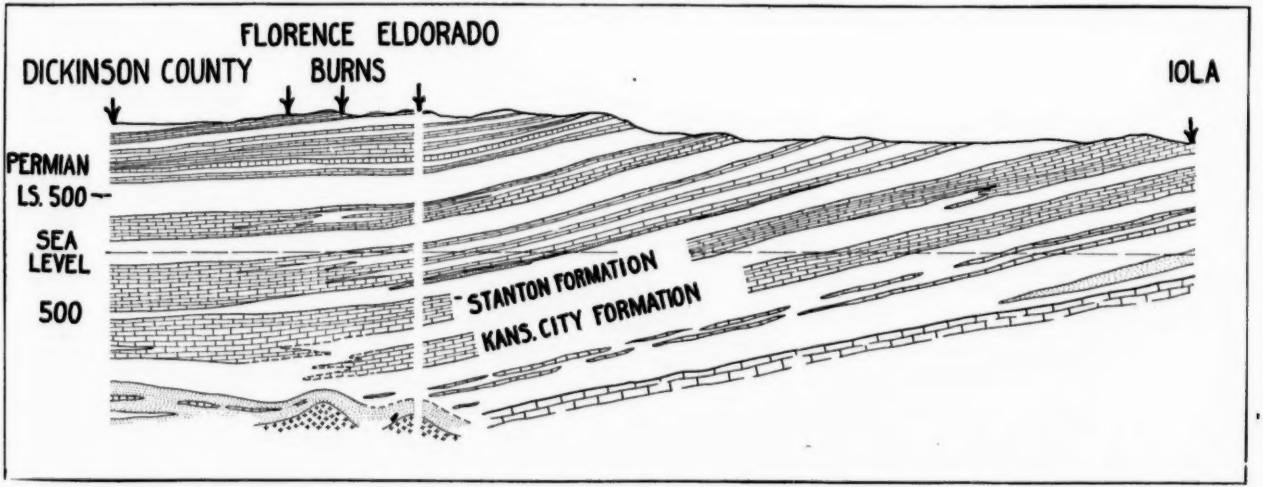


Plate VII. Section extending east-west from Iola to Eldorado, Kansas, and thence north to Dickinson County, Kansas, showing gradation in character and thickness of sediments, compiled from 50 well logs.

in Texas, and according to Beede,[30] possibly equivalent to the upper portion of the Magdalena of New Mexico. The distribution of oil in these formations is somewhat similar to the arrangement of oil shown in the previous map.

Following Kansas City—Stanton times of Kansas, there comes a marked break in the character of sediments throughout east central and northern Oklahoma (Plate IV *H*). It is just previous, or during this time that the Arbuckle Mountains are thought to have been formed as shown by the Seminole conglomerate, which has been traced from the region of Sulphur, Oklahoma around the north flank of the Arbuckle Mountains into the red, sandy sediments between the Dewey limestone and the Pawhuska limestone of northern Oklahoma.[31]. The sandy nature of the sediments present in Kansas is evidenced by the massive sandstones of eastern Chautauqua County. Plate V indicates that the limestone character of the basin migrated northwest across the granite hills of central Kansas at this time.

An explanation as to the uplift of the Arbuckle Mountains is suggested by Plate VIII which shows accumulated stresses due to the loading of the sediments. Such a loading could result in the northwest-southwest folds throughout the area from Ada, Oklahoma, to an area probably south of Red River in Montague County, Texas. The folding of the Arbuckle Montains differs from that of the Ouachita Mountains in that the Arbuckle folds and faults are normal instead of parallel to the direction of settling previous to compression. It is suggested that this difference is due to the wedging in the lower Paleozoic sediments, where these were thickest; and since the path of thick early Paleozoics lies at an angle to mid-Pennsylvanian settling, folds would be formed normal to the direction of settling across the lower belt of sediments. In the case of the Ouachita movement, the wedging was probably started in the thick Stanley and Jackfork sediments, so that the direction of equal wedging and the

[30]Beede, J .W., Letter to the writer.

[31]See also Moore, R. C., Bull. Am. Ass'n. Pet. Geol., vol. 5, pp. 32-47, 1921.

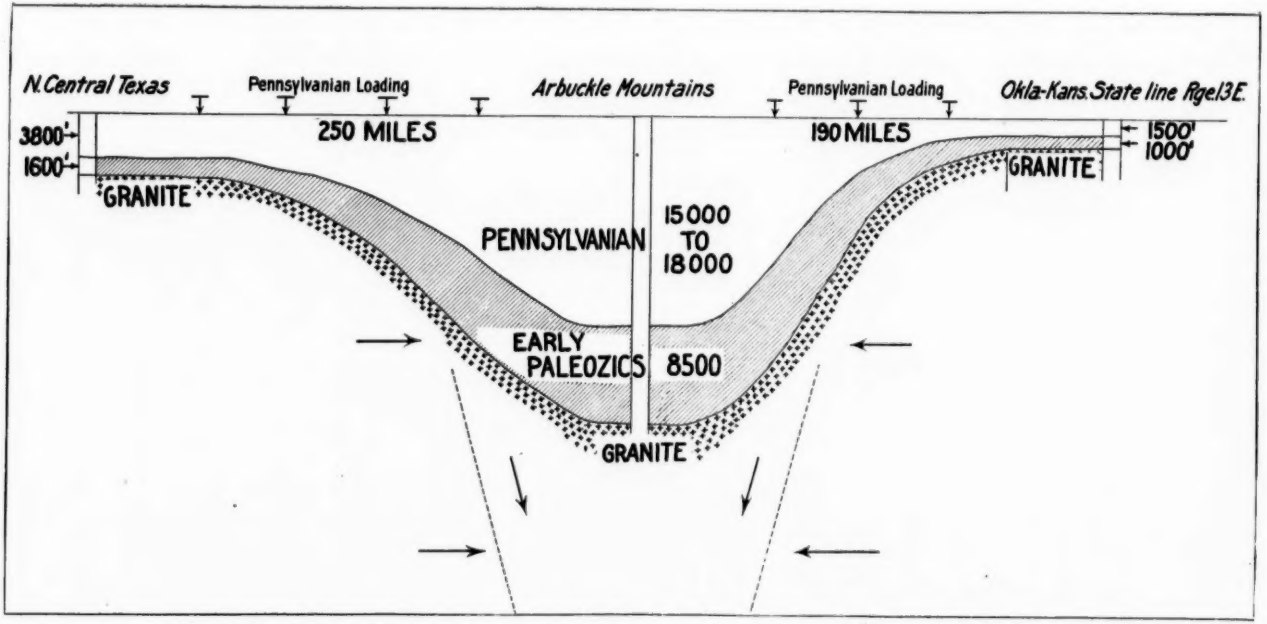


Plate VIII. Northeast-Southwest hypothetical cross-section from north-central Texas across Oklahoma showing position of loading relative to the thickness of sediments and also the resulting accumulative stresses just previous to the Arbuckle Mountain folding.

alignment of sinking due to overloading of sediments were parallel.

The arrangement of oil in these sediments extends from Greenwood and Cowley counties, Kansas, to Blackwell, Oklahoma, as well as from eastern Elk County, Kansas to Newkirk, Ponca City, and Garber, Oklahoma. It is possible that the Gotebo field is furnishing oil from these sediments, although definite evidence is entirely lacking. The oil formations of Stephens, Cotton, Caddo, and Comanche counties, Oklahoma, are thought to be older than the Stanton limestone of Kansas. A colection of fossils examined by D. K. Greger, from a blue, limey shale at a depth of 1,900 feet in the Walters District, furnished five Pennsylvanian species, none of which is found later than the Severy shale, and all of which are more abundant in Henryetta and Kansas City time.[32] Furthermore, the sediments formed by the Arbuckle Mountains north to the Kansas line are composed largely of conglomeratic sands, barren shales, and occasional limestones, with practically all reddish sands south of the Cimarron River. If the mountains had such an effect for this distance north of the basin, it is highly improbable that bituminous shales and suitable oil sediments would be formed as close to the mountains as Stephens and Cotton counties, Oklahoma.

Plate IV *I* illustrates possible conditions following the deposition of the Herington limestone in Kansas and Oklahoma and during part of Wichita and San Andreas time in Texas and New Mexico. It is at this point in geological history that the Wichita Mountains are thought to have been formed although direct stratigraphical field evidence in that district is entirely lacking, due to overlapping younger sediments. By referring to Plate III, it will be noted that the Wichita Mountains are in the path of the thickest Paleozoic sedimentation and that a subsiding basin during late Pennsylvanian and early Permian time, crossed this path in the vicinity of the Wichita region. The natural outcome expected would be another series of folds similar in nature to the Arbuckle

[32]Fossils of Cisco age have recently been found in a core from a well in the Loco field.

Mountains. The alignments of folds in the Wichita Mountains is not exactly parallel to those in the Arbuckle Mountains. Such a condition strengthens this hypothesis because the alignment of stresses in the shifting of basins of the Pennsylvanian would not necessarily move parallel to former positions. This also accounts for the disconnected portion of the old basin in a relatively low area north of the Wichita Mountains in which "red beds," salt, and gypsum would naturally accumulate. Occasionally marine connections might be established around the edges of the Wichita Mountains and consequently marine fossils would possibly occur in thin zones of the resulting formations. Marine conditions represented by prominent limestones and shales predominate south of Wichita Mountains, although reddish sediments are common immediately south of the mountains.

Attention may be called to a partially enclosed basin which probably would be a favorable area for inland lakes. This area lies east of Llano, and west of Sabine and south of Ouachita and Arbuckle Mountains. It is worthy of note that the salt dome region of Texas lies in the eastern and southeastern portion of the state which practically coincides with the area just mentioned. Consequently, it seems plausible that the great portions of salt formed in the salt dome district might have originally been deposited in late Pennsylvanian and Permian times. This idea is merely a suggestion but it seems possible if this sketch of Pennsylvanian paleogeography is correct.

Thus, it will be noted that the Pennsylvanian seas began as narrow channels through the former Paleozoic "lows" and progressively moved out of the eastern and central part of the United States by a slow oscillating series of basins. The stresses of sedimentation developed throughout Paleozoic time have culminated as the very thick sediments in the Pennsylvanian were deposited. A series of successive mountin-making movements was developed, the results of wnich have controlled the paleogeography and the physiography of this country to the present time.

PROBABLE ORIGIN OF PETROLEUM IN THE SHALE

Most oil geologists believe that petroleum was originally deposited as some form of solid bituminous matter in the shale of certain classes of sedimentary rocks. Drilling in the Mid-Continent district has shown that the most favorable areas for oil accumulation are in a typical series of marine deposits with some limestones and thin sandstones but consisting largely of blue and some black bituminous shales or black limestones. A thick series of rapidly deposited clastic sediments does not offer such a favorable section of rocks. The greatest amount of oil is produced from a series of marine sediments which was apparently formed in a quiet, low protected portion of an inland basin. Such a place is usually removed from a zone of rapidly accumulating clastics, and favorably located for deposition of organic debris by littoral currents. A suitable area of this nature is illustrated especially well in Plate IV *D* as the Pennsylvanian basin begins to move up into the Cherokee trough of northeastern Oklahoma and southwestern Kansas.

David White[33] has argued that the reason for the absence of oil in the Pennsylvanian sediments of the Arkansas trough is on acount of metamorphism or change in the sediments which has produced an increased fixed carbon ratio of the coals, and consequently, a loss of the volatile hydrocarbons. The author wishes to ask if such a change in the carbon ratio might not be the result of original sedimentation or of a process of drying and solidification before the sediments are deeply buried, rather than to metamorphism from mountain movement. An example which appears decidedly contradictory to White's hypothesis is found in the Arbuckle Mountain region. Here oil is discovered in a series of sediments which most certainly have been very highly folded practically at the very foot of these mountains. Furthermore, it is a decidedly heavy oil. The barren sediments of the Arkansas trough are only slightly folded, the dips ranging up to 10 to 15 degrees, and yet they furnish practically no oil. Un-

[33]White, David, Some relations in origin between coal and petroleum, Wash. Acad. of Sci., vol. 6, pp. 189-212, 1915.

fortunately, there are no coals to be examined in the Glenn formation of southern Oklahoma. However, the sediments of the Glenn formation show in the zones of the asphalt sandstones, the typical marine columnar section desirable and such a section is not present in the sediments of the Arkansas trough. Consequently, the author is inclined to believe that carbon ratios are intimately connected with the early stages of consolidation. Typically marine sediments—such as limestones, blue and black shales, and some sandstones—dry and lithify by a process which is probably favorable for the retention of the lighter hydrocarbons. Sediments of a thick clastic nature are more frequently above the water level and the lighter hybrocarbons, if formed in appreciable amounts, could more easily escape. Shore lines and lines of equal carbon ratio are usually parallel. However, the evidence of the Mid-Continent district, especially in the vicinity of the Arbuckle Mountains opposes the hypothesis that increase in the carbon ratio has been effected by folding of the sediments. This change in carbon ratio seems more closely allied to the original character and proximity to shoreline of the sediments.

From the standpoint of Pennsylvanian paleogeography, the most favorable places for bituminous shales to have been formed would be the north end of the inner Bend basin; the west side of the early Pennsylvanian trough extending across Love, Jefferson, Cotton, Stephens, Carter, Garvin, Murray, Pontotoc, Hughes, Seminole, and Okfuskee counties, Oklahoma, the area immediately southwest of this zone in Texas; and the Cherokee basin extending from Muskogee, Okmulgee, and Creek counties, Oklahoma, north and east into southeastern Kansas. Favorable zones higher in the section would be expected to the west and north as the quiet parts of the seas gradually oscillated to the west.

DISCUSSION OF THE MORE DETAILED PROBLEMS IN OIL ACCUMULATION

In a former paper,[34] the author has taken up in detail a

[34]McCoy, A. W., Notes on principles of oil accumulation, Jour. Geol., vol. 27, pp. 252-262, 1919.

theoretical discussion of the principles of oil accumulation, taking due consideration of field evidence to the effect that the majority of producing horizons throughout the Mid-Continent area are closely associated with bituminous beds. It is unnecessary to repeat this theoretical discussion, but it seems desirable to insert here a few detailed examples which led to the experiments described and to the conclusions reached in that paper.

The final statements in this detailed discussion are:

1. Bituminous shales are in close relationship with the producing sand of an oil field.

2. This bituminous material is in solid form and is only changed to petroleum in local areas of differential movement.

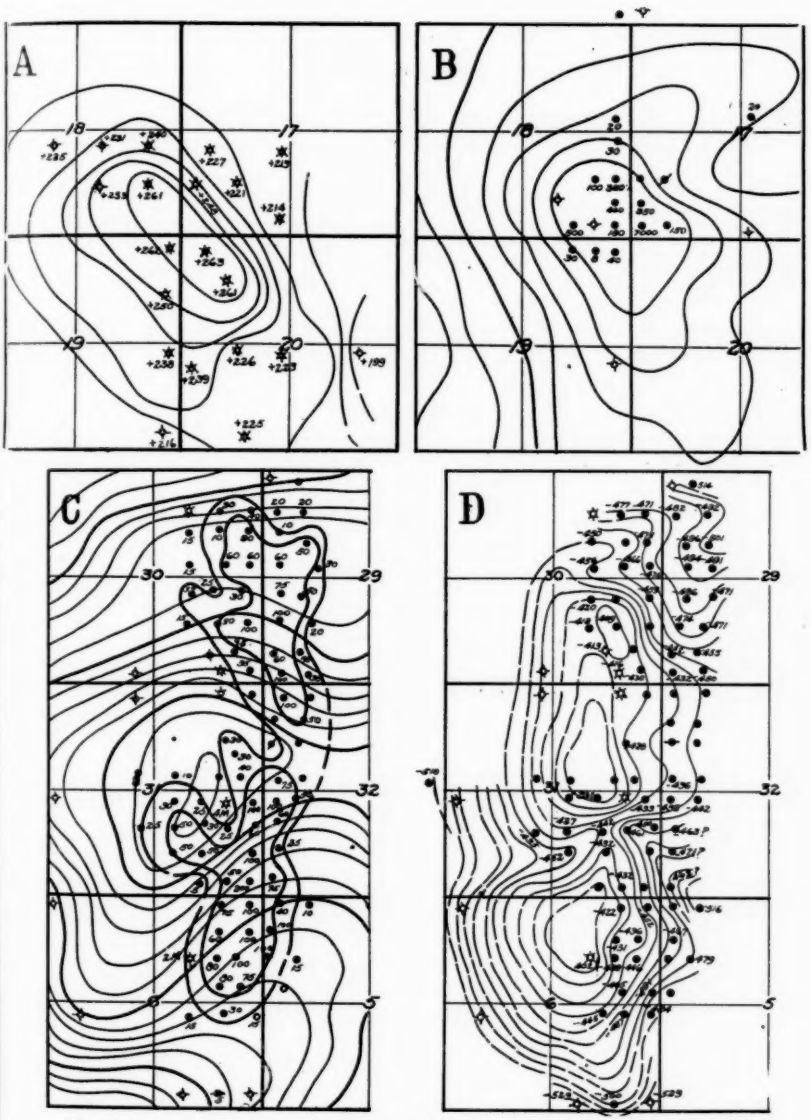
3. After such a change is made, the accumulation of oil into commercial pools is accomplished by capillary water; and this interchange only takes place in local areas where the oil-soaked shale is in direct contact with the water of the reservoir rock. Such conditions may be accounted for either by joints or faults.

4. After the oil once reaches the sand, some adjustment takes place until the oil has found the larger openings and then it remains in them indefinitely.

5. The amount of oil in any field could have been derived from normal shales in close proximity to the pay horizon.

6. These five statements also lead to another general conclusion: that areas of maximum differential movement are in accord with anticlinal structures. It has been noted from a study of the majority of pools in the Mid-Continent field that the maximum sub-surface faulting is found on the flanks and sides of the anticlines, and that the best production runs in trends parallel to the faulted zones. It has also been noted in a number of cases that production which is not related to marked anticlinal or dome structure bears the same close relation to sub-surface faults.

Plate IX *A* presents the subsurface elevations on the shallow gas sand in an Osage County field, Oklahoma. Contour lines have been drawn to represent the doming or subsurface structure as worked out on the gas sand. The best gas wells in this sand were as follows: the well in the NE¼ SE¼ Sec. 18, the well in the SW corner of Sec. 17, the two wells in the NW¼ Sec. 20, and the well in the NE¼SW¼ Sec. 20. From the nature of the contour lines it will be noted that the best wells align parallel to the steep northeast dip crossing the SW¼ Sec. 17 and the NE¼ NW¼ Sec. 20. It will also be noted that there are four producing gas wells on the low side of this northeast steep dip, all of which are lower structurally than the dry holes in the W½ SE¼ Sec. 18, and the NE¼



Maps of two producing oil and gas fields showing relation of production to structure and to shore lines

SE¼ Sec. 19. These dry holes are higher on the structure but further removed from this steep northeast dip. Some water was encountered in the gas sand by the dry holes. This northeast dip could possibly be interpreted as a fault or series of faults since it is in the same alignment as numerous faults throughout the Osage.

The surface contours of the same structure and the initial productions of wells drilled to a deeper horizon which was productive of oil, are presented, in Plate IX *B*. It will be noted that the area of best production is practically in line with the steep northeast dip shown on the subsurface map on the gas sand. The second location west of the SE corner of Sec. 18 is a dry hole and this well is drilled as near the top of the structure from a surface and sub-surface standpoint as any of the other wells. This one exception to this best alignment of production with the steep dip is the third location from the SE corner of Sec 18, which was reported a 500 barrel well; but immediately northwest of this well a dry hole was drilled. East of this well is the dry hole already mentioned and south and southeast of the well are two very small producers. Consequently, this well is rather a freak well but may be located on a slight dip on the southwest side of the structure similar to the one on the northeast side and not so extensive.

By referring to the previously mentioned paper on the principles of accumulation, it will be seen that the production in the gas sand bears out the identical conditions shown by the experiment performed on accumulation by faulting. Furthermore, the deep production has held well to this single structural feature, with one exception. This case is cited for several reasons. The prominent structural break can be seen readily from the subsurface structure map. The gas production parallels this break on the high and low sides, but is more prolific on the high side. The west side of the structure, which by most geologists is considered the path of accumulation, is barren at higher elevations than the production on the east side. There is no oil in the gas horizon to interrupt segregation of oil. Dry holes occur in both horizons on the top of the structure but far enough removed from the structural break

to be readily accounted for by the principles of accumulation discussed.

Most structures in the Mid-Continent are built up around several breaks, and where these breaks are comparatively close together, production spreads from one to another over a rather wide area. The steep dips are much more prominent on the southwest side of the average structure, and experience has shown that the best production generally is located on the west flank.

In passing from the west central Osage east into Washington and Nowata counties, a more complex arrangement of structural breaks or steep dips is encountered. West of R. 11 E. in Oklahoma, practically all of the structural breaks have a northwest-southeast alignment parallel with the faults of the district, as shown by Fath,[35] Heald[36] and others. Throughout eastern Osage, Washington, Nowata, Tulsa, eastern Creek, and Okmulgee counties, Oklahoma, there seems to be a combination of a number of such breaks, in different alignments, on the subsurface structures of producing sands. The production is also closely allied with these breaks, although some times extending in a very complex arrangement.

Plate IX *C* and *D* show examples of this nature where there are steep dips running in a northeast-southwest as well as northwest-southeast direction. This structure also shows less relation of oil accumulation to doming and again demonstrates the closely association of production with steep dips on the east side of the structure. The west side is barren.

In fields where the sub-surface elevations do not disclose marked dips, the production generally trends in richer zones in the regional stress lines.

Attention is now called to the fact that the faulting in R. 11 E., and to the west has a northwest-southeast alignment, while that along the contact of the Pennsylvanian and the Mississippian is northeast-southwest. The zone of intersection of these two sets of stresses would lie throughout Ok-

[35]Fath, A. E., The origin of the faults, anticlines, and buried "granite ridge" of the northern part of the Mid-Continent oil and gas field, U. S. Geol. Surv., Prof Paper 128 C, 1920.

[36]Heald, K. C., et al, Structure and oil and gas resources of the Osage Reservation, Oklahoma, U. S. Geol. Surv., Bull. 686, 1920-1.

fuskee, Okmulgee, eastern Creek, Tulsa, eastern Osage, Washington, and Nowata counties, Oklahoma. From casual inspection of a production map of Oklahoma it will at once be noted that most of the widespread production lies in this area of intersecting stresses. West of this area there are some widespread fields, but these upon analysis are associated with numerous parallel steep dips or probable faults in a north-

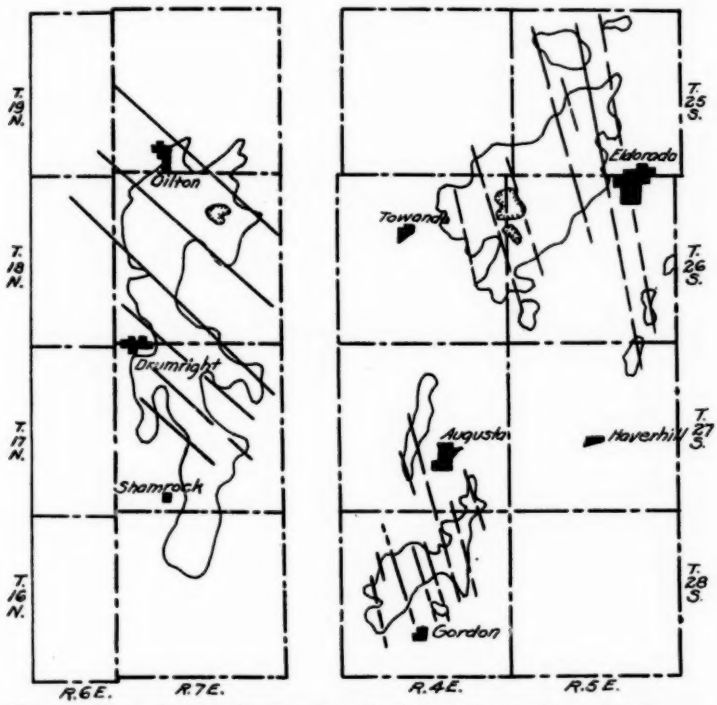


Fig. 1. Maps showing limits of production in the Cushing, Oklahoma, and Eldorado, Kansas, oil fields with lines of steep dips which suggest subsurface faulting.

west-southeast direction, which are so closely grouped that production apparently has spread from one to the other. The ElDorado and Augusta, as well as the Cushing field are examples of this nature. Figure I illustrates the subsurface

steep dips worked out in these fields, and the relation of the limits of production to these general lines.

A further point of evidence in the surface structure of Oklahoma is that the widespread production east of R. 10 E. is less conformable to doming or elevation of the sand, but decidedly complex in its extent. To the west the fields are quite markedly associated with structure, as most of these steep dips cross the flanks of the domes or anticlines on the northeast or the southwest side.

If these structures are the results of settling, as has been inferred by the author[37] and later discussed by Blackwelder,[38] or of slight horizontal movement in the lower beds as thought by Fath[39], it seems reasonable to expect doming to result between faults or dips which could develop on either side of some buried core. In this case, production, if not on top of the structure, is found on the flank, or closely associated therewith. The structures and groups of stressed zones are more or less isolated from each other.

East of R. 10 E. where there are intersections of many lines of weakness in complicated arrangement, there is much more opportunity for production to be widespread and unconformable with structure, according to the principles of accumulation previously stated.

A closer study of the producing fields will show a more exact alignment in the direction of the basin than formerly mentioned under the short discussion of the paleogeography. An excellent structure at cross-direction of the basin trend from a producing structure may not produce at all in the same horizon as the productive structure. The sand may be present, but evidently the columnar section has converged or expanded in going crosswise of the basin. In areas where this convergence is slight, similar structures may produce over quite a width normal to the direction of the basin; but the greatest

[37]McCoy, A. W., Discussion Am. (Southwestern) Assoc. Pet. Geol., vol. 1, p. 110, 1917.

[38]Blackwelder, Eliot, The origin of the Central Kansas oil domes, Am. Assoc. Pet. Geol., Bull. vol. 4, No. 1, pp. 89-94, 1920; Powers, Sidney, Op. cit. p. 121.

[39]Fath, A. E., Op. cit.

linear extent of groups of fields in the same sand is parallel with the direction of the basin.

An example of convergence and divergence of a columnar section is shown in Plate X. This represents a summarized group of formations extending from the structures at Oxford and Red Bud, Kansas, across the Augusta and El Dorado structures, the Burns structure, and to the structure in T. 17 S., R. 17 E., Kansas. The equivalent of the producing horizon of ElDorado and Augusta is present in all the structures mentioned as a very prominent limey sand carrying water. The Pennsylvanian beds which overlie this horizon, pinch out successively northward. The area of production is at ElDorado and Augusta where the relative distance between the producing horizon and the Kansas City or Stanton formations remains constant. To the north this section has decreased, and to the south the section has increased. Production is obtained in neither direction from ElDorado and Augusta, although good structure and the same porous reservoir are present.

Attention is next called to the fact that the shales which overlie the producing horizon at ElDorado and Augusta appear more important than the producing horizon itself. The structural breaks in the vicinity of ElDorado and Augusta are probably capable of showing a relation of rich shale to the porous sand in such a manner that production results. To the north, the shales have possibly either pinched out or changed in character. To the south, the shales, if present are too far removed vertically from the porous zone for structural breaks to cause accumulation. The strict anticlinal theory, considering long distance migration, can in no way account for such a marked difference in producing and non-producing structures along this zone. In all cases there are excellent folds and the porous horizons are present and most probably are completely connected. The change in the columnar section above the reservoir rock is the only prominent difference geologically in this line of folds. The structural breaks and problems of convergence and divergence of columnar sections are intricate problems of historical geology.

ORIGIN OF STRESSES.

In the next few paragraphs some points are cited as suggested reasons for the geographical distribution of stresses. The principal folding in the several parts of Oklahoma and Kansas which affects the oil districts is described:

The folds and faults of the Tahlequah axis run northeast and southwest through Sequoyah, Cherokee, Adair, Mayes, and Delaware counties. These folds extend westward into the lower Pennsylvanian of Wagoner and Muskogee counties, but they are covered unconformably by younger beds in the Pennsylvanian which are of middle and upper Cherokee age. Previous discussion of stress lines associated with oil production has mentioned a similar line of folds and faults in the productive sands of lower Cherokee age throughout a region generally east of R. 10 E. of Oklahoma. The folds of the Tahlequah axis are compression folds, and the faults extend on the surface for long distances. The origin of these faults and folds results from the Tahlequah uplift.

The folds of the Arbuckle and Wichita Mountains extend northwest and southeast throughout the middle and lower Pennsylvanian formations of southwestern Oklahoma. These folds have been eroded, and the majority of them covered unconformably by late Pennsylvanian and Permian beds. Folds in the Permian or later beds which overlap the area affected by the Arbuckle and Wichita folds, are most likely due to settling of the sediments over an irregular erosional topography. The explanation of the earlier movement has been briefly mentioned in a previous discussion of the formation of the Arbuckle and Wichita Mountains.

The area of northeastern Oklahoma throughout Okfuskee, Creek, and eastern Osage counties, shows a marked series of normal faults which aligns in a northwest-southeast direction. From subsurface studies of producing sands, similar stress lines have been noted as far west as Garber and Blackwell. They extend into Washington, Nowata, Tulsa, and Okmulgee counties.

The alignment of steep dips which seems to be the controlling feature of production in central Kansas along the

"granite ridge" is a little north of west, and east of south, at an angle of about fifteen degrees. The alignment of best production bears a close relation to this trend of weakness in the ElDorado, Augusta, Elbing, Peabody, and Covert-Sellers districts. It is also in evidence at the Teeter, Salyards, and Fox-Bush fields. How far northwest-southeast stress lines of northeastern Oklahoma extends into Kansas is not definitely known, nor is the exact distance of the southeastern extension of the probable subsurface fault alignments along the "granite ridge" definitely established. Several other lines of faulting or folding which affect oil accumulation may be present throughout Oklahoma and Kansas, but to date these mentioned seem to be the most prominent.

The faults along the "granite ridge" as well as the faults described by Fath[40] were evidently caused by some different character of stresses than those associated with any mountain-making movement in this district. Fath has suggested that horizontal slipping on the basement rock of the Pennsylvanian sediments may have accounted for the formation of these faults. The author does not deny this as a physical possibility. However, attention is drawn to the fact that the Oklahoma faults occur in the sediments between the Henryetta and about the base of the Ralston series. Very few faults have been mapped near the top of the Ralston series, and only one or two, possibly, in the Permiam limestone of the western Osage. These limestones furnish excellent key horizons, and if the faults were present, they surely would have been detected. The lower formation even as far as Blackwell and Garber show the presence of this faulting. Evidently the adjustment of such stresses had been completed before the deposition of later Ralston and Permian beds.

Beginning with Henryetta (lower Marmaton) and extending up into Stanton times, there was definitely a sinking basin in southeastern Kansas. This is shown by the constant recurrence of thick limestone, which pinches out both to the northeast and to the southwest.

Plate V shows the rapid increase in thickness of the sedi-

[40]Fath, A. E., Op. cit.

ments to the south equivalent to the zone between the Deer Creek-Topeka series, and the Fort Scott limestone. Especially does this increase materialize south of Arkansas River in Oklahoma along Rs. 7-8 E. Along Rs. 11-12 E., the increase is not so noticeable. There is good reason to think that after the Arbuckle Mountains were formed, a considerable thickness of sediments were deposited just north and northwest of the present hills, and such deposits have probably been overlapped by the extention of the Permian limestones.

Considering the two conditions just mentioned, the area of Osage, Tulsa, Creek, and Pawnee counties acted as a fulcrum for tension in the lower sediments since they were sinking both to the northeast and southwest, to accomodate the particular sedimentation of that time. The relief of these tensile stresses would be the opening of faults and cracks in a northwest-southeast direction about in line of the average faults now shown on the surface in this district. The fulcrum would not remain at one definite place but would oscillate with the changes in the seas. Consequently, relief faults should be expected from the north part of Okfuskee, Lincoln, and Payne counties, throughout the area northeast across the Kansas state line. The pronounced faulting would be most prominent in the sediments below the Fort Scott, (Oswego) limestone and would probably be associated with the irregular "highs" of the hard formations below the top of the Mississippian. Pennsylvanian sediments, being soft, would rapidly adjust themselves to this structural arrangement and the majority of the faults would materially effect the sediments up to and including the Pawhuska limestone. In many cases the faults would not extend entirely to the surface in the Pennsylvanian rocks, but would be reflected by strong dips, and many local structures would result throughout the area.

By the time a large portion of the sediments were eroded from the Arbuckle Mountains to the north, Permian limestone seas extended farther to the south than had the seas of Pennsylvanian time. The accumulation of sediment north of the Arbuckle Mountains was not so rapid and the limestone forming seas had probably moved farther west in Kansas. Consequently, the tensile stresses heretofore described are ob-

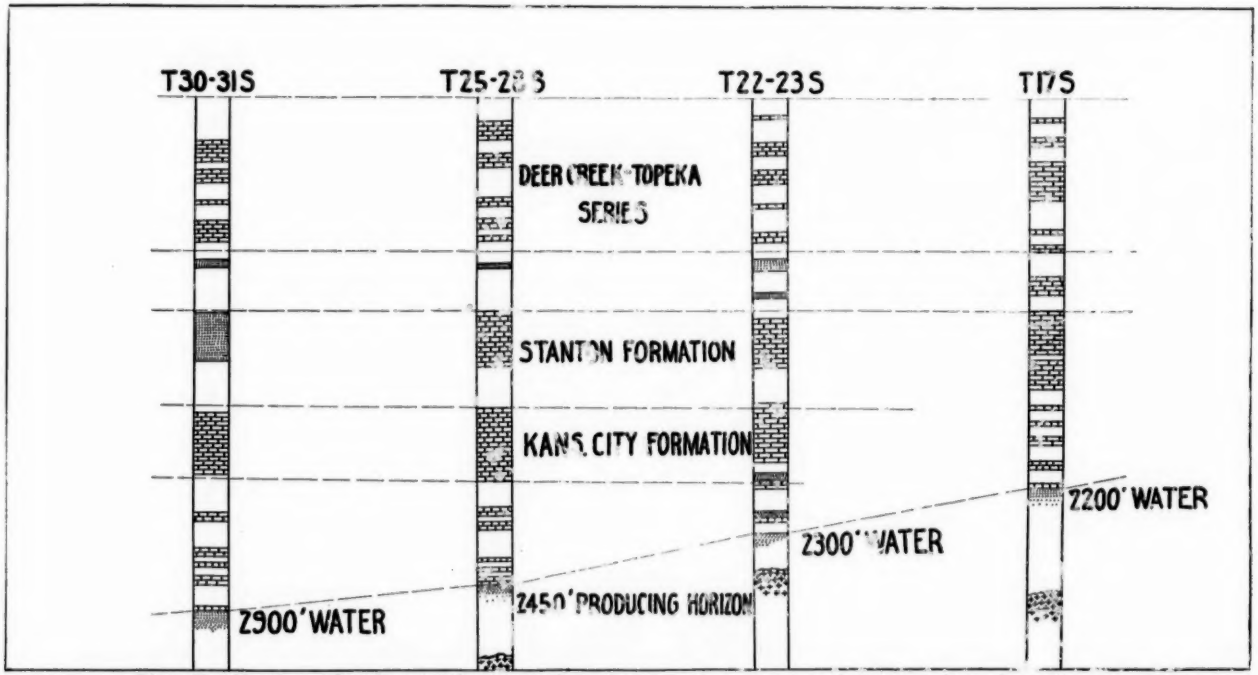


Plate X. Northeast-Southwest columnar sections showing average interval changes shown by well logs in Lower Pennsylvanian strata along the crests of granite structures in central Kansas.

literated and faults should not be expected in the sediments of the upper Ralston and Permian formations. The upper formations would settle over faulted areas thus forming structures throughout the western Osage, Kay, Noble, Garfield, and Grant counties, Oklahoma. Some faulting might accompany this settling, but such movement would be entirely subsequent to the regional adjustment.

By the same principle of tensile stresses developed by settling basins, faults would be opened up on the flanks of granite cores of central Kansas. The Kansas City and Stanton seas were the first Pennsylvanian basins to settle both to the northeast and west of the "granite ridge." During these times tension faults for adjustment would be started in almost a north-south direction off the granite "highs." At later times as the basin migrated to the west, sediments of the upper formations would settle down over the faulted areas with marked dips. The settling would adjust itself largely to the granite topography, but faulting would probably be developed primarily in the direction mentioned. It should be understood that faults developing by the process just described would not continue for great distances. The maximum extent would probably be only a few miles, and the tendency to "scissor" might be expected. Groups of faulted zones might extend for quite a distance in the direction of faulting, but the faults themselves would be individual and largely disconnected.

It is noteworthy that the production in both directions of these regionally stressed areas bears a marked relation to the direction of faulting. Thus, the historical geology with its practical applications explains this relation in a plausible manner.

CONCLUSION

The Pennsylvanian paleogeography of the Mid-Continent district is in a broad way intimately associated with the production of oil . The application of the principles of sedimentation in connection with the paleoeography are helpful in considering regions favorable for exploration. The districts for oil accumulation are those which possess a columnar section of sedimentary rocks largely of marine origin, consisting

predominantly of shale, with some limestones and sandstones, and marked by rich bituminous beds throughout, in close relation to porous horizons.

The structural features which apparently control production are better understood and can be studied from a more scientific standpoint by following closely the historical geology. Two conditions seem essential to the production of oil: the proper type of sediments, and marked local structure.

It is hoped that by this paper the petroleum geologists of this country will appreciate the need for considerable research along these or other lines in order to develop the science into a more exact and definite group of well-organized facts.

The one suggestion for safest wildcat exploration, although by no means an infallible one, appears to be that after a rank wildcat test has proven production in one horizon, investigation of the area should be extended in the direction of the shore line of that age, and location of test wells should be made on structural features similar to that of the first producer. If thought is given to this idea for development, it is easily understood why the "practical producer" has played his "trends" or "forty-five degree lines" with considerable success, though without comprehension of the scientific meaning of what he learned through his experience.

BULLETIN OF THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS

OUTLINE OF THE GEOLOGY AND DEVELOPMENT OF THE PETROLEUM FIELDS OF PERU, SOUTH AMERICA, WITH NOTES ON OTHER OCCURRENCES IN THE PERUVIAN REPUBLIC

By V. F. Marsters

INTRODUCTION

The fact that an important petroleum industry has been developed in Peru during the past fifteen years or more, is regarded as sufficient reason for presenting to this Association a brief account of personal observations while engaged in an official capacity with the Peruvian Government, together with additional data collected since that period. Under the plans formulated by Senor M. A. Denegri, at that time Chief of the Cuerpo de Ingenieros del Peru, it had been arranged to make —first, a reconnaissance survey of all the petroleum-bearing deposits of the Republic, particularly those then known on the coast, and second, to follow these preliminary studies with a detailed investigation of the more important areas, both producing and promising. Only the first part of the plan was completed. So far as the writer is aware, the proposed detailed survey and investigation of stratigraphical problems has not even been initiated. It is to be hoped, however, with the growing importance of this unique Republic, with its production steadily increasing for some years past, that it will nevertheless receive the attention due this important national resource. Nothing could be more timely at this period than a detailed investigation not only of the present producing territory, but of other sections which are known to be promising, and results obtained should be published in full, because such a step could not fail to serve the commercial interests of the Republic.

Location of Petroleum Fields. The present producing oil fields of Peru are located in the two most northern provinces

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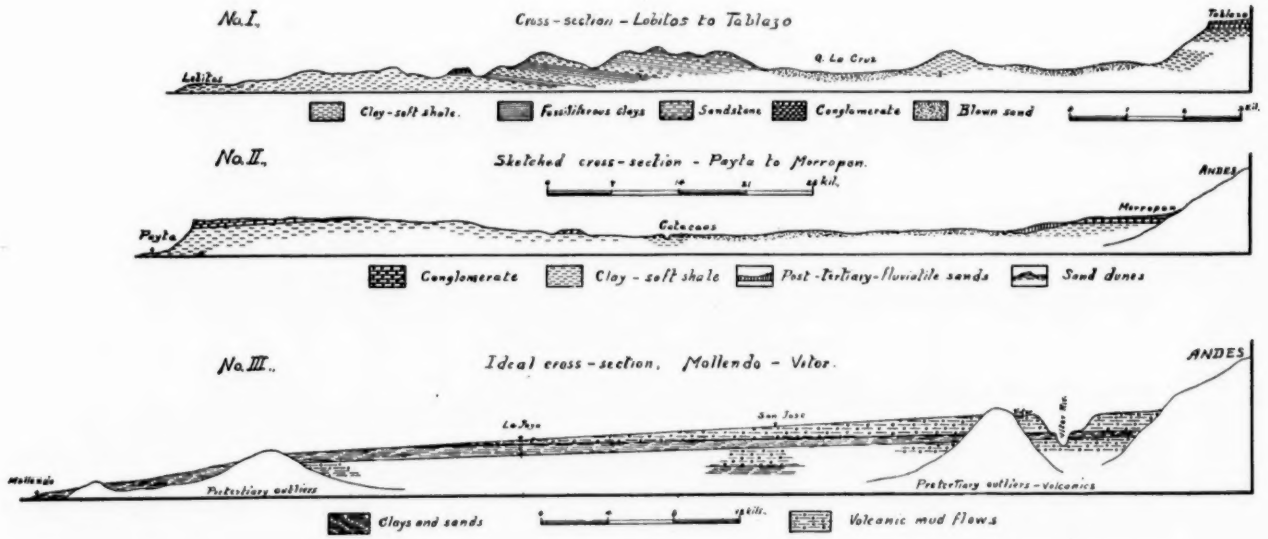
of the Republic, namely Tumbes and Piura. The province of Tumbles lies adjacent to the Ecuador boundary, and the department of Piura joins it on the south.

EARLY HISTORY OF THE PERUVIAN OIL FIELDS

The first information concerning the occurrence of petroleum on the north coast of Peru, according to documentary evidence, came from a Spanish priest known as Padre Acosta. He had noted the existence of "cope" or "bua" somewhere in the vicinity of Cabo Blanco and probably at points along the coast as far as Negritos. This information was communicated to Spanish sea captains who did not fail to let these facts be known at home. It is known that the Spanish mariners were acquainted with these occurrences early in the history of Spanish rule of Peruvian territory for both on the shoreline and later in the locality known as La Brea, the "bua" or "la brea" as it was then known, was obtained. At the interior locality near the southwest end of Cerro de Amotape pits and ditches were sunk into the sands and clays where "bua" would seep into the bottom of these excavations. It proved to be a heavy black asphaltic product which was used extensively by the Spaniards for painting ship bottoms. Even when serious development work began in the Negritos oil fields, it was customary on the part of the natives to gather considerable quantities of "la brea" boil it down to a pitchy consistency and use it on surface materials as a paint.

Details of successive ownership of this territory as a Spanish grant, down to the time first development work was undertaken by the London Pacific Petroleum Company follow:

In 1692 the Spanish Crown made a grant of the entire area between Tumbes and Chira rivers to a Spanish sea captain, Matin Alonzo Grandino. Somewhere between 1692 and 1705 this block of land fell into the possession of one Juan Benito de las Heras who in 1705 transferred the entire domain to the Hospital de Belan in Piura. In 1826 it became the property of the State and in 1827 was sold to a Peruvian, Senor Riego de Lama. There is some evidence that it was acquired from the State by one Senor Quintana who in turn transferred it to Senor Lama. The next step was a division of this huge area into thirteen parts and the allotment by Senor Lama of one of these to each of his sons and daughters. The allotment containing La Brea fell to Senora Josefa Lama. In 1878 it was transferred to


No. I.
Cross-section – Lobitos to Tablazo
Lobitos
Q. La Cruz
Tablazo
Clay-soft shale.
Fossiliferous clays
Sandstone
Conglomerate
Blown sand
No. II.
Sketched cross-section – Payta to Morropon.
ANDES
Morropon
Payta
Cabeceas
Conglomerate
Clay-soft shale
Post-Tertiary-fluviatile sands
Sand dunes
No. III.
Ideal cross-section, Mollendo – Vitor.
ANDES
La Joya
San José
Mollendo
Pretertiary outliers
Pretertiary outliers – volcanics
Clays and sands
Volcanic mud flows

Genaro Helguero and in 1888 to Herbert Tweddle with all mineral rights committed therewith. This last owner brought about the establishment of the London Pacific Petroleum Company now in operation at Negritos.

The block in which the Zorritos oil field is located is believed to be part of the Mancora Block as laid out by Senor Lama. An attempt was made to develop an oil industry there before our Civil War by a New York company. However, it was not until 1870 that a certain Henry Smith started serious prospecting and obtained some production in the vicinity of Zorritos. In 1875, Senor Faustino Piaggio, a prominent Italian business man located at Callao, Peru, became interested in the project and is now the sole owner of the Zorritos field.

The Lobitos oil field is located some twenty-five miles north of the Negritos field. Data concerning the transfers of this allotment to the time when it was acquired by the Peruvian Corporation in 1901, have not been obtained. At all events prior to 1901 a concession was obtained by the Lobitos Oil Company and under the control of the Peruvian Corporation serious development began in 1901 but no appreciable production was obtained until 1905.

In Quebradas Heath and Grau, northeast of Zorritos about four kilometers from Santa Rosa, an attempt was made to develop an oil field. The work was begun in 1891 by a company formed in London, known as the Heath Petroleum Company. This company failed to find anything of importance. In 1895, Don Francisco Miranda who formed the London Company, succeeded in forming a new company known as the Compagnie de Petrole del' Amerique du Sud with a capital of about three million francs. This company is reported to have obtained some little production, but failed to find enough to make the proposition one of any commercial importance. The company ceased activities in 1897. Much of the surface materials such as boilers, pipe, etc., were later acquired by the Lobitos Oil Company, during the earlier stages of its prospecting period.

The only locality in the Peruvian Republic outside of the Coastal Plain of northern Peru that has been proved to be oil-producing is located on the west edge of the inter-Andean Plains extending from the north end of Lake Puno, department of Puno. The Brown Brothers of California, who are responsible for the work done there, obtained some production, but its location is so far in the interior and the cost of transportation to the coast is so high that with only modest production it was impossible to put this enterprise on a paying basis.

GEOLOGY OF THE COASTAL PLAIN OF PERU

The coastal plain of northern Peru extends from Zarumilla

on the north to Rio de Sana on the south and covers the shore-line belt through the three provinces of Tumbes, Piura and Lambayeque. It reaches its maximum width in the central part of the province of Piura where the plain proper attains a width of 150 kilometers.

To the south of Rio de Sana, the foot hills of the Andes approach the shore line. They, together with small outliers sometimes surrounded by a thin coat of the coastal plain sediments, stand out as sentinels and guards of the massive and towering range to the rear. These outliers may also constitute a small low ridge adjacent to the shore-line with only a narrow belt of coastal plain separating it from the main range of the Andes.

Where the larger streams heading on the high plains between the eastern and western Andean ranges, reach the coast line, they encounter in some places large embayments which extend into the edge of the foothills. These embayments are usually filled with coastal plain deposits, of which the inner edge and sometimes the central belt as well, are covered by post-Tertiary or flood plain deposits. A fair example of this phase of coastal geography is shown by the small sketch map of the valleys of Jequetepeque, Pacasmayo and Seco in the department of Libertad. This map shows the location of the shoreward edge of the Andes proper and the flood-plain character of the valley floor to the coast line. The greater part of this plain is irrigated and supports successful agricultural industries. A still better illustration is shown in Chicama and Moche valleys where the embayments are typical and the foot hills of the Andes proper reach the actual shoreline.[1]

Lima, the capital of the Republic, stands on the inner edge of the flood plain of Rimac River. From Tambo de Mora to Lomas on the south there is another belt showing a very considerable development of coastal plain[2] as shown on the accompanying map (Plate 1.)

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[1]Bulletin 71, Condiciones Hidrologicas de los Valles del Libertad, 1909, V. F. Marsters.

[2]Bulletin 70, Informe Sobre La Costa Sur del Peru, Cuerpo de Ingenieros de Minas del Peru, 1909, by V. F. Marsters.

Topographically, the coastal plain of northern Peru, exhibits its greatest development in the province of Piura. The area between the towns of Payta, Sullana and Piura, forms a broad table-land with its shore edge scored by short valleys. This table-land shows an elevation of some 350 to 400 feet at the shore line, but decreases toward the interior in the region of Piura and Catacaos. It forms a vast plain with scarcely a scratch on it except for the action of wind blown sands which form groups of sand dunes or "medanos," as they are locally known. To the south this plain which is known as the Despoblado de Payta, gradually falls to the level of Rio de Piura approximately 150 feet above sea level at Catacaos.

The great desert basin to the south and east of Rio de Piura forms a low lying plain much of which is covered by sand dunes, especially the coastal and central portions, together with a belt on the east side of Rio de Piura extending practically from Sechura and Catacaos. Southeast of Cerro de Yllesca the shoreline stands very little above sea level. With heavy winds from the west and southwest inundations sometimes cover great stretches of these low-lying belts. Even at considerable distance from the actual shoreline, repeated flooding of these lowlands, with rapid evaporation of the sea water under a strong tropical sun, has resulted in the development of salt deposits of no mean proportions. Along the inner rim of the coastal plain province or on the east part of Desierto de Piura and Desierto de Olmos, the original surface of the plain has been slightly cut by small streams extending within its limits and finally lost in the arid plains to the west.

North of the Chira Valley, post-Tertiary elevation has been sufficient to bring about very considerable dissection, indeed to such an extent that the uppermost member of the Tertiary sediments has been removed from a very considerable area. Along a belt in the interior from Lobitos and to the northeast, portions of the original plain formed by the upper Tertiary member remain intact.

Along the shoreline from the mouth of Chira River to Zorritos considerable erosion and dissection of the plain has taken place, the strongest relief being developed in the Ne-

gritos area, to some extent in the Lobitos area and sections around Mancora and in the Zorritos area. Standing above the general level of the coastal plain, a number of pre-Tertiary knobs and ridges form prominent points of view along the shore line. These knobs and ridges are composed of pre-Tertiary rocks, which are partially buried by the coastal plain sediments. The two most important of these ridges are known as Cerro de Payta and Cerro de Yllesca.

GEOLOGY OF THE TUMBES-LAMBAYEQUE COASTAL PLAIN.

The formations entering into the make-up of the Tumbes-Lambayeque Plain are composed, so far as the writer has been able to determine, of Tertiary sediments. The uppermost member is exposed very clearly in the cliffs behind the town of Payta, where it caps underlying clays and sands, the latter being regarded as belonging to the middle member of the Tertiary series (See cross-section, Plate 2). The cliff extends northward to the south side of the Chira Valley and to the south of Payta where it comes in contact with the basal portion of Silla de Payta.

The uppermost member is composed of conglomerates, gravel alternating with beds of clay, the finer grained strata containing a fairly large range of fossils. The maximum thickness of the member noted on the Payta plains was approximately 60 feet. It thins out toward the interior or across the Despoblado de Payta and in the direction of Piura, but may be seen again at various points in the interior and to the northeast of Negritos. It forms the high plains northeast of Lobitos and even remnants may be seen forming table-lands or mesas within a short distance of the Lobitos oil field. East and northeast of Zorritos the upper member of the Tertiary was not recognized. On the south end of the coastal plain the uppermost member of the Tertiary was not found on the coast line, but remnants of it may be seen along the inner belt from points north of Cerro de Calera or on the east side of Desierto de Olmos. It extends with more or less irregularity northward and along the northeast edge of the Desierto de Piura. This horizon has in turn been covered in

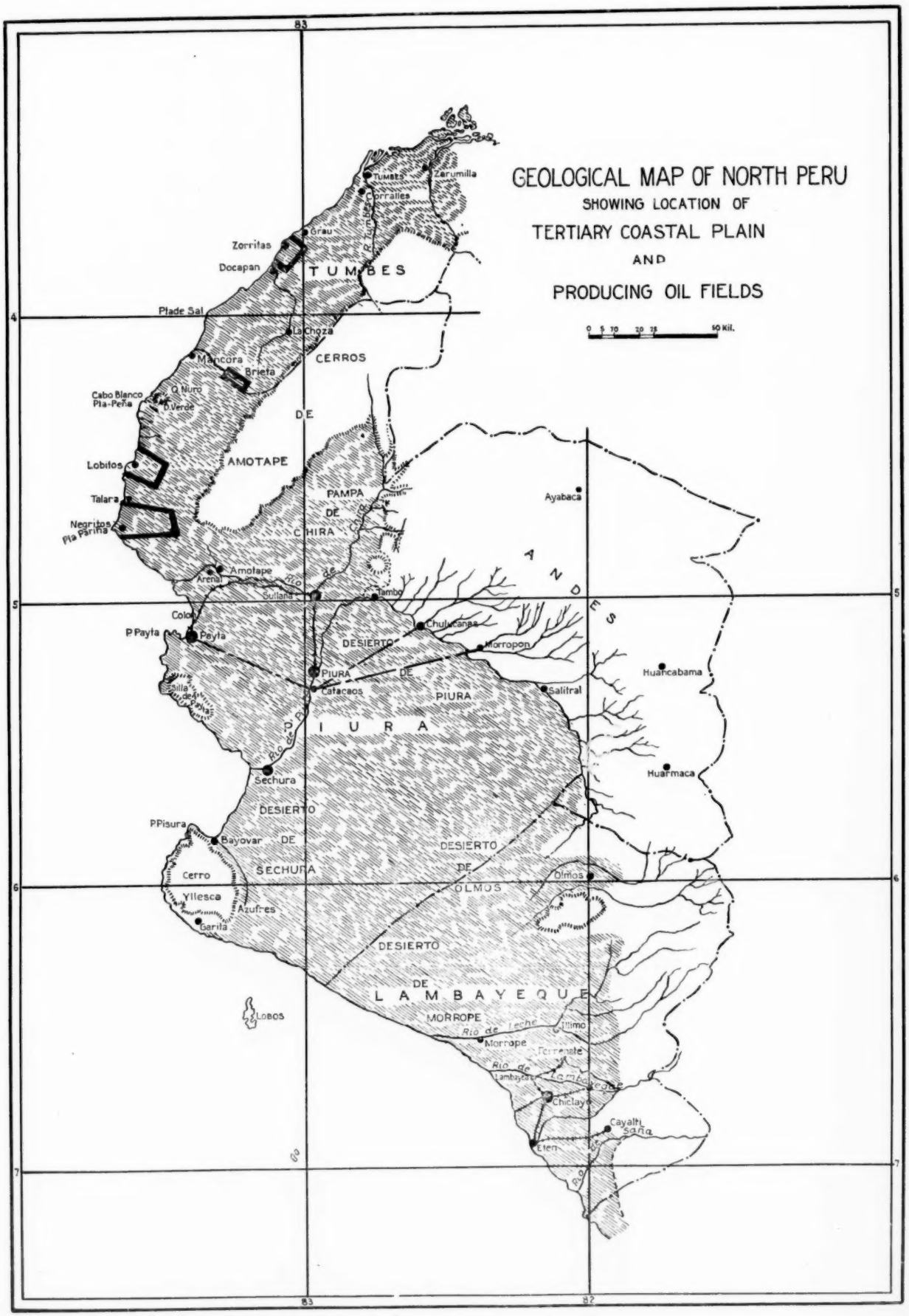
part at least by post-Tertiary deposits and subsequently cut through by the present drainage system.

It is interesting to note in this connection that the Chiclayo-Lambayeque area, composed in part of the Tertiary sediments, has been covered to a very large extent by post-Tertiary fluviatile deposits. This physiographic coincidence has furnished the conditions for the development of the largest rice industry on the west coast of South America. The rice culture covers in the main, the areas occupied by parts of distributaries while on the floors of the tributaries where irrigation is possible cane raising and related industries are being conducted on a large scale.

Along the shore line from Silla de Payta to Tumbes, one will find exposed below the uppermost member a very considerable thickness of clay and sand and sandy clay formations, with here and there local lenses of coarse sand and pebbly or even coarse conglomerate. Excellent exposures may be seen in the cliffs to the rear of Payta at Colon, Punta Parinas, Cabo Blanco, to a lesser extent in the lower cliffs south of Zorritos and also in Quebradas Grau and Charan, northeast of Zorritos. From this point northeastward the topography decreases in relief to the valley of the Tumbes. by the same series of sand and clay deposits as noted at Zorritos and Cabo Blanco. They also cover the flat area between Tumbes and Zarumilla. This series of comparatively soft sands and clays, the writer has regarded provisionally as Middle Tertiary.

A fairly abundant fauna occurs in the Middle Tertiary horizons at points between Negritos and Talara and also in the interior from Lobitos. They are largely gastropods and nautiloid forms, some of the latter being exceedingly large and well preserved.

From the data the writer had at hand at the time he conducted the work for the Peruvian Government, he concluded that the middle member approximated something like 650 feet in thickness. This conclusion was based in part upon an investigation of well logs made available by the companies operating in Negritos, Lobitos, and Zorritos fields. Below 650 feet, it was discovered from an inspection of a limited


GEOLOGICAL MAP OF NORTH PERU
SHOWING LOCATION OF
TERTIARY COASTAL PLAIN
AND
PRODUCING OIL FIELDS
0 5 10 20 25 50 Kil.
83
82
4
5
6
7
TUMBES
CERROS
DE
AMOTAPE
PAMPA
DE
CHIRA
DESIERTO
DE
PIURA
DESIERTO
DE
SECHURA
DESIERTO
DE
OLMOS
DESIERTO
DE
LAMBAYEQUE
ANDES
Tumbes
Zarumilla
Corrales
Grau
Zorritas
Docapan
R. Tumbes
Pta de Sal
La Choza
Mancora
Brieta
Cabo Blanco
Pta-Peña
O Muro
O Verde
Lobitos
Talara
Negritos
Pta Parina
Amotape
Arenal
Sullana
Tambo
Colan
P Payta
Payta
Chulucanas
Morropon
Ayabaca
Huancabama
Salitral
Huarmaca
Olmos
PIURA
Catacaos
Bayovar
Sechura
P Pisura
Cerro
Yllesca
Azufres
Barita
Lobos
MORROPE
Morrope
Ferrenafe
Lambayeque
Chiclayo
Cayalti
Saña
Eten
Ptillo
Río de Piura
Río de Chira
Río de Tumbes
Río de Lambayeque
Río de Leche

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number of well logs, that the formations became firmer and that the sands and clays each increased in thickness. It also appeared that there was some noticeable variation in the depths at which the deeper formations assumed a more indurated character. It is believed, therefore, that an unconformity exists between the softer and predominantly argillaceous middle member and the firmer lower member. In other words the Tertiary sediments of the northern coastal plain appear to be made up of at least three distinct members with an unconformity between them. The thickness of the lower members at any point along the shoreline belt or within the range of drilling operations, has not been determined so far as the writer knows. From some rough structural data collected in a section extending from Bocapan to the inner edge of the coastal plain and also in the Negritos section it is calculated that the entire series of Tertiary sediments may approximate 4000 feet or more in thickness along the shoreline.

STRUCTURAL CHARACTER OF THE ZORRITOS OIL FIELD.

From field data it was found that the Zorritos field lies on the southeast of an anticline the greater part of which apparently extends beyond the present shore-line. Southeast dips can be seen along the bordering cliffs and for short distances into the interior. Some faulting can be seen at various points on the east slope of the structure. In the region of Bocapan, gas springs may be traced along a line of probable faulting. South of this line and in the immediate vicinity no attempt has been made to develop possible oil-bearing territory.

STRUCTURAL CONDITIONS IN THE LOBITOS FIELD.

In the Lobitos oil field, the Middle Tertiary member is well exposed and the upper member caps the tableland or higher plain in the interior. At a few points along the shoreline, the southeast dips disappear and in places the normal northwest dips appear. The reversals or southeast dips may be traced several kilometers into the interior. In other words, we have fairly clear evidence of anticlinal structure on the land side of the shoreline instead of the seaside as in the Zorritos field.

In the Lobitos field, some complications have been brought about by faulting. With the exception of possibly two lines

of displacement, however, these may be regarded as local and they do not materially affect the general structure of the field as a whole. It is also quite possible that more than one structure exists in the Lobitos field. The accompanying cross-section, Pl. II, No. 1, shows the structure observed in that part of the field where faulting does not appear to play any important role.

STRUCTURAL CONDITIONS IN THE NEGRITOS FIELD.

In this field there is clear evidence of anticlinal structures but these are more variable in form and more disturbed by local faulting than in the Lobitos field. Along the coastal belt from Negritos to Talara, there is a general northeast to southeast dip, which is exceptionally strong at certain points. The dips decrease as the shoreline is approached and at points on the playa small northwest dips may be seen. This is fairly clear proof that the folding in this field is anticlinal, but only a small part of the west or northwest side of the structure lies on the land side of the shoreline. In the region of La Brea there is probably an independent structure. The surface conditions are such, however, that full and satisfactory data with which to work out this problem cannot be obtained. The writer believes that monoclinal structure exists along the inner part of the coastal plain in the region of La Brea. There is also reason to believe that similar structural features extend around the Amotape spur and into the Chira Valley. So far as known, no drilling to any appreciable depth has been done within the limits of the Chira Valley.

STRUCTURAL FEATURES IN THE PAYTA-PIURA-OLMOS AND MORROPE DESERTS.

In the vicinity of Payta, where both the upper and middle members of the Tertiary are exposed, there is evidence of greater elevation than in the region of Piura, Catacaos and Sechura, maximum elevation having occurred along a line from Colon to Silla de Payta but decreased in amount to the interior. (Pl. II, No. 2). In the interior, along the edge of the foot hills, from Tambo Grande to Salitral, post-Tertiary elevation has taken place to variable degrees. From Salitral south to and beyond Olmos, the same post-Tertiary

elevation has occurred but with greater variation than to the north. In the central part of the coastal plain, south and east of Piura River, there is a broad lowland covered here and there with large areas of slow traveling sand dunes. If the upper member of the Tertiary has ever been developed to any extent in this part of the plain, it has been removed and the Middle Tertiary clays and sands have become somewhat eroded, these small valleys having later been filled with drifting sand. Occasional evidence of existing structural conditions can be found in limited exposures of the Middle Tertiary in this particular section. The writer believes that further detailed investigation of the central belt may bring to light information of interest and value bearing upon the question of petroleum possibilities of the Payta-Olmos-Morrope deserts.

A large part of the coast-line between Garita and Morrope is covered by sheets of drifting sands and practically no prominences containing exposures of either Upper or Middle Tertiary are to be found. From a physiographic point of view, it is believed that a very thick series of Tertiary sediments lie between Cerro de Yllesca on the northwest and Eten and Rio Sana on the southeast. It is probable that an even thicker series of sediments (Tertiary) exists here, than in the Negritos section.

THE PIRIN AREA.

The only additional locality, apart from the northern oil fields, where petroleum has been produced in commercial quantities, is near Pusi or Pirin, department of Puno. This point may be reached by rail from Mollendo to Juliaca where the line joins the Cuzco-Puno railway. From Juliaca, the Pirin area lies some 20 kilometers north and east of the railway junction.

The accompanying map (Fig. 1.), shows that this field lies on the northwest edge of the Lake Titicaca plains. At the north and northwest end of this huge inland lake a broad plain extends practically from Juliaca to Huancane, but it is broken at various points by small ridges and knobs. This plain is but a part of the great inter-Andean surface which

is geographically known as the High Plains. The formations composing these plains are at least in part Tertiary. They partially fill the valleys which extend north and northwest from Lake Titicaca.

In the Pirin area, the Tertiary beds have been subjected to considerable folding and faulting. It is here that report of the natives concerning oil springs and seapages, first led to serious investigation. The area from which structural information may be obtained is about ten kilometers long and three or four kilometers wide. The small amount of data collected by the writer suggests that monoclinal structures with faulting is a characteristic feature of the Pirin area.

So far as known, most of this region has not received much consideration from the petroleum geologist. The area occupied by the High Plains sediments, covers a considerable territory beyond the limits of the Pirin area. The sediments are known to show oil indications at many other points, at Huancane, where there are seapages from sediments clearly belonging to the plains deposits. There are also shales in the Huancane region which appear to be oil-bearing. They are older than the Tertiary and may be Cretaceous in age.

In the vicinity of Maravillas, Ricardo Duestua reports the occurrence of seapages under geological conditions similar to those known in the Pirin area. The same writer also refers to seapages in the region of Pallpata in the District of Pichigua and another in the district of Pocpoquella from which a sample was taken and analyzed.[3] The analysis[4] shows 5 percent paraffin and 12.8 percent kerosene (no benzine). Again in the region of Chuquibambilla in the province of Lampa a repetition of the same class of occurrences can be seen.

The rather large areal distribution of surface indications would suggest that much of this territory might be worth detailed investigation.

THE TAMBO DE MORA-PISCO-NASCA COASTAL PLAIN.

As was indicated in the first part of this paper there is but one other section of the Peruvian coast line where is

[3]Estado Actual Y Porvenir de la Industria Petrolifera en el Peru, 1912, Por Ricardo A. Duestua, p. 12.

[4]Idem. p. 11.

found a development of coastal plain geologically similar to the Tumbes-Lambayeque area. From Tambo de Mora a short distance south of Callao to Lomas, a distance of approxi-

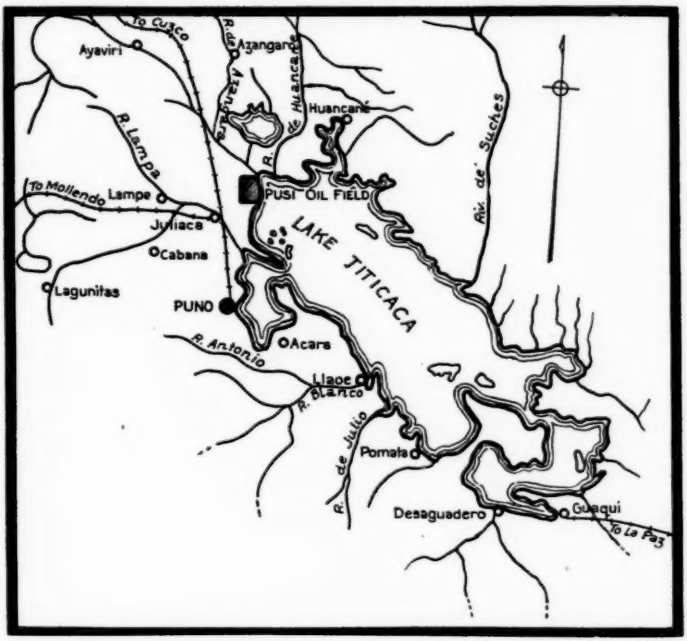

Fig. 1. Map of Lake Titicaca region showing Pusi oil field.

mately 250 kilometers, the shore line is dotted with knobs or lined with low ridges composed of pre-Tertiary formations. Behind these littoral ridges, the coastal plain, with variable elevation and broken here and there by partially buried hillocks, extends eastward to the actual edge of the Andes proper. The fact that the plain is repeatedly broken in its continuity by protruding hills suggests that the Tertiary formations entering into its structure do not as a whole attain any great thickness in this section. The points where the maximum thickness of these Tertiary sediments may be expected, are: (1) somewhere in the Pampa de Chunchango

and northwest of the Pisco-Ica railway, (2) in the Pampa de Hanyuri south of Ica and along the trend of the lower part of Ica River, and (3) in the Pampa de Tunga opposite the Bay of San Juan or between San Juan and Cerro de Tunga.

In this part of the Coastal Plain there are two localities where indications of petroleum have been found: (1) on the lower part of Ica River, and (2) at a point South of Nasca known as Portachuelo Grande. In the first case, sands and arenaceous clays, clearly Tertiary in age, were found impregnated with an asphaltic substance. In the second case, a limestone was found which was apparently partly filled with petroleum, for when broken it yielded a strong odor of oil. The areal extent of this horizon is not known nor were sufficient data obtained to prove its age although it may be Cretaceous.

THE OCONA-AREQUIPA-MOQUEQUE SECTION OF THE PERUVIAN COASTAL PLAIN.

So far as known no petroleum indications have been reported from this area. In this connection, it is important to note that the coastal rim in this section, where at all well developed, is largely composed in many of its parts of huge mud-flows interbedded with sand and clay. The high but well defined plains extending from Pampa de Cuno-cuno, through Pampas de Sihuas Vitor and Joya exhibit very thick and fine exposures of sediments, mud-flows, etc., on their inner edges and near the foot hills of the Andes.[5]

Where the larger streams have cut far below the level of the coastal rim one can see that the mud-flows are a predominant part—in fact so much so that in some sections they extend from within the foot hills of the Andes to the flanks of the coastal ridge. (Pl. II, No. 3).

In the Tambo River section the plain narrows down to a bare connection through Pampas de Tambo and Colorado with the much larger and broader plains of Pampa de

[5]Photographs showing these relations accompany in an article by V. F. Marsters, Physiography of the Peruvian Andes, Annals New York Academy of Science, Vo. 22 Sept. 1912 pp 225-258, Plate 31.

Clemesi. From this point it can be traced without any very great break to the Chilean border. The formations constituting Pampa de Clemesi and others to the south are largely clays and sands with mud-flows decidedly subordinate. Although there is no evidence of oil occurrences in this part of the coastal province, salt deposits of remarkable purity exist at various localities and it is not at all improbable that other non-metallic substances of commercial value may be developed, as requirements of the future demand.

ADDITIONAL INDICATIONS OF PETROLEUM DEPOSITS.

Since the date of the writer's investigations of Peruvian territory, a number of locations showing seapages and impregnated asphaltic sands have been noted in publications of the Cuerpo de Ingenieros de Minas del Peru. In a report by Ricardo Deustua reference is made to seapages in the vicinity of Chimbote as well as on the Lobos islands opposite Chiclayo. As the coastal plain deposits in the region of Chimbote are somewhat limited, it is not probable that promising petroleum territory, will be found in this section.

PRODUCING PETROLEUM FIELDS OF PERU.

The main oil fields of Peru are as follows: (1) Zorritos field; (2) Lobitos field; (3) Negritos field (including the Lagunitos and La Brea areas); (4) La Brieta area (Hacienda de Fernandez), and (5) Pirin or Pusi area.

ZORRITOS FIELD.

The Zorritos area is a dome located 25 kilometers southwest of Tumbes on the shore line and at a point bearing the same name as the company. As stated in the historical note, some prospecting had been done in this region even before the period of the Civil War in the United States, but serious development did not start until Mr. Piaggo of Callao, Peru, acquired a controlling interest in the field about 1875. A little later he became the sole owner. The field has been producing to greater or less extent to the present day. Data concerning holdings, number of producing wells, depths drilled and number of producing sands will be found below (Table No. 1). Most of the production obtained in the Zor-

ritos field during its earlier period of development was refined at Zorritos. Later Mr. Piaggio erected a refinery at Callao where practically all of the Zorritos oil is being refined and sold to local markets. Total production of crude is shown in Table No. 2.

LOBITOS FIELD.

The Lobitos area is located on the shore line about 35 to 40 miles southwest of Zorritos (See Pl. I). From 1901 to 1905 very considerable prospecting was carried on, shallow wells only being drilled. This development was done under the direction of the Peruvian Corporation. About 1905 the Lobitos Oil Company assumed control of the development and began an extended drilling campaign. By 1912 the company had 105 producing wells. The character of some of those drilled between 1910 and 1912 is shown in the tabulation below.

Results of Deep Drilling in the Lobitos Oil Field, 1910-1912[1]

Wells	Drilled in	Initial Prod. Flowing	Settled Production	Date settled Production	Depth of wells
No. 100	Mar., 1910	300 bbls.	100 bbls.	Mar., 1912	2,600 ft.
No. 127	July, 1911	40 bbls.	36 bbls.	Mar., 1912	3,046 ft.
No. 152	Feb., 1911	30 bbls.	15 bbls.	Mar., 1912	2,743 ft.
No. 153	Sept., 1911	40 bbls.	25 bbls.	Mar., 1912	2,580 ft.
No. 169	Jan., 1912	500 bbls.	400 bbls.	Mar., 1912	2,070 ft.

[1] Data from Mineral Resources of the United States, 1912. 110 deep wells were drilled during this period.

At the close of 1917 the company had obtained 143 producing wells, with producing sands from depths varying from 400 to 2500 feet. Not less than four sands are found. The main part of the Lobitos production is shipped on the company's tank steamers to California refineries. The general table (No. 1) below shows details concerning wells, sands, production etc.

OTHER FIELDS

Negritos Field. This field received its first real impetus in the early 90's when Herbert Tweddle transferred his interests to the London Pacific Petroleum Company and they at once started serious prospecting. In 1907 this company had drilled 206 wells but how many of these were actually productive is not known. In 1914 they had drilled a total of 730 wells, 480 of which were productive. In 1917 the company reported 695

producing wells, including the wells of the Lagunitos area. When the International Petroleum Co., the Lagunitos Oil Co., and the West Coast Fuel Co., obtained interests in the Negritos field activities in this region were greatly increased. By 1914 no less than seven distinct sands had been found. The deepest well reported was drilled in 1914 and reached the depth of 3900 feet.

The London Pacific Petroleum Company holds the largest oil concession in the Republic of Peru, amounting to approximately 1,723 square kilometers or 43,075 pertenencias or claims. A part of their production is refined at Talara, the shipping port of the company and the remainder is shipped to refineries neaar Vncouver, British Columbia.

La Brieta Area. This area is located about 25 kilometers toward the interior from Mancora. It has been known for some time that outcropping sands and sandy clays to the southeast were impregnated with asphaltic substances, but in 1906 or about that time a Mr. Taiman drilled a well on his own hacienda to a depth of 455 feet and tapped, according to data submitted, four distinct sands at 90, 140, 196, and 442 feet. Some production was obtained but it proved to be a heavy black asphaltic oil. So far as the writer is aware no further exploration has been made in this locality.

Pirin or Pusi Area. The Pirin or Pusi area is located on the northeast edge of the plain surrounding the north end of Lake Titicaca department of Puno. Work has been carried on by Brown Brothers of Los Angeles, California, who acquired 58 claims about 1902. They had drilled 10 wells by 1905 probably 5 of which yielded a little production. Oil sands were found at depths between 250 and 700 feet. The deepest well is reported to have reached 1,500 feet. The oil obtained in this area differs from that of the northern fields in that it possesses a parafin and not an asphaltic base.

Garita Area. Garita is located on the southwest corner of Cerro del Yllesca, department of Piura. Some years ago an attempt was made by H. Patton Johnson and Capt. T. P. Murphy to test this ground. A standard rig was erected and drilling was carried on intermittently for ten years. Al-

though no original records were obtained, it was reported that the well was drilled 800 feet and quit in very hard rock. No proof was ever obtained concerning the existence of oil or gas sands in this test.

TABLE NO. 1

Peruvian Oil Fields	Dates	Number Claims[1]	Total No. Wells	Total Prod. Wells	Max. Depth Drilled	Depths Prod. Sands	Number Prod. Sands
Caleta Grau. (Heath)	1897	58	26	13[1]	1608[2]	157- 626	3
Zorritos	1907		266	23[3]	200	194-1640	3
Oil fields	1911			50[4]			
	1914	266	313	43			
	1915						
	1916						
	1917						
	1918						
	1919		920	29			
	1920						
Negritos	1907		206		1680	45-1340	
Oil fields	1911			297[5]			
	1914	1723sq. k[6]	730	480	3900	300-3000	7
	1915						
	1916						
	1917			695[7]			
	1918						
	1919			732			
	1920						
Lobitos	1907		20	16	2250	400-1500	7
Oil leld	1908			26			
	1909			62			
	1911			101	3435		
	1912			105			
	1913			110			
	1914	4120[8]	195	114		400-2500	4
	1915			119			
	1916			131			
	1917			143			
	1918			143			
	1919			118			
Hacienda Fernandez (La Brieta)	1907		1		455	90- 442	4[9]
Lagunitos							
Oil field	1913	2560A[10]		10[11]			
	1914						
	1919		261	230			
Pirin field							
Lake Titicaca	1905	58	10		1500	250- 700	

[1]Reported by a member of the French Company
[2]Although one well was reported to have been drilled to a depth of 1,608

COMMERCIAL CHARACTER OF PERUVIAN PETROLEUM

Classified information may be found in a publication on Peruvian Petroleum, by Ricardo A. Duestua. From a commercial point of view the production in the northern fields will fall somewhere within the limits of the following statement: napthas and gasoline, 15-25 per cent; kerosene, 20-24 per cent; from the remaining distillate, lubricating oil, 20-30 per cent; asphaltic base. An incomplete analysis shows in part the character of oil from the Pirin field: gasoline, 0-7 per cent; kerosene, 7-20 per cent; lubricants present in large amounts, no figures available; paraffin base.

PRODUCTION

The following tabulation shows the annual production of the various fields of Peru as well as th total annual production for the Republic from the earliest date for which reliable figures can be obtained, to the present. From an inspection of the figures, it will be seen that the Negritos field including the Lagunitos area as well, is far in the lead. Lobitos takes second, while Zorritos holds third place.

TABLE NO. 2

PRODUCTION OF PETROLEUM IN PERU, 1896-1920, BY DISTRICTS

Year	Lobitos	Negritos	Zorritos	Dept. Puno Pirin	Dept. Puno Lagunitos	Production Total
1896						47,536 bbls.
1897						70,831 bbls.
1898						70,905 bbls.
1899						89,165 bbls.
1900						274,800 bbls.
1901						274,800 bbls.
1902						286,725 bbls.
1903						278,092 bbls.
1904						290,123 bbls.

feet, most of them did not exceed 500 feet.

[3]At this date there was one **flowing** well, the remainder (22) being on the pump.

[4]Three flowing wells.

[5]All pumping wells.

[6]1,723 sq. kilometers would contain tbout 43,075 pertenencias or claims. One pertenencia is approxmately 10 acres (200 meters by 200 meters.)

[7]Including all producers in the Lagunitos area as well.

[8]The Lobitos Oil Co. acquired a very considerable block of oil land in Ecuador In 1918 this company drilled a well to a depth of over 2,000 feet.

[9]The acreage under development by the Laguntas Oil Co. is part of the original concession under the control of the London and Pacific Petroleum Company.

[10]A number of the wells first drilled in the Lagunitos area produced large amounts of gas. This helped to decrease the amount of petroleum used as fuel and correspondingly increased the total amount of oil shipped from the Negritos field.

[11]Property of the Titicaca Oil Co., owned by Brown Bros., Los Angeles, Calif. Operation began around 1905, reached its maximum production 1909. No figures are available on production since 1915.

[12]Oil-bearing sands were found at 90, 140, 196, and 442 feet. Reported by the owner, Mr. Taiman.

1905	75,000[1]	335,160	37,720			447,880	bbls.
1906	162,000	330,510	42,419	1,365[1]		536,294	bbls.
1907	279,000	396,750	65,476	15,000[1]		756,226	bbls.
1908	319,898	543,750	71,429	76,103[1]		1,011,180	bbls.
1909	421,195	740,070	70,750	76,103[1]		1,316,118	bbls.
1910	400,083	773,025	107,000	50,000[1]		1,330,105	bbls.
1911	391,290	882,698	94,048	30,000[1]		1,398,036	bbls.
1912	587,048	1,071,000	87,095	15,000[1]		2,133,261	bbls.
1913	557,355	1,136,490	83,343	10,000[1]	346,073	2,133,261	bbls.
1914	504,743	1,032,210	88,136	10,000[1]	282,713	1,917,802	bbls.
1915	664,972	1,355,925	72,736	1,000[1]	392,618	2,487,251	bbls.
1916	654,060	1,822,733	73,852		[2]	2,550,645	bbls.
1917	686,595	1,771,560	75,262		[2]	2,533,417	bbls.
1918	639,098	1,820,814	76,190		[2]	2,536,102	bbls.
1919						2,616,000[3]	bbls.
1920						2,790,000[4]	bbls.

THE POSITION OF PERU IN WORLD PRODUCTION.

From the following tabulated statistics referring to the South American Republics and Trinidad, it will be seen that Peru holds the lead in petroleum production in South America.

According to the statistics presented by the American Petroleum Institute for 1919, the production of Trinidad was slightly in excess of the total for Peru, but the figures of the United States Geological Survey places Peru in the lead by more than a half million barrels for this year. The world production by countries for 1920 as outlined by the American Petroleum Institute gives Peru the ninth, Trinidad the eleventh. Argentine the thirteenth, and Venezuela the fourteenth position in the world series of total annual production.

Petroleum produced in South American Republics and Trinidad, W.I., in barrels

STATISTICS FROM U. S. GEOL. SURVEY

Date	Peru	Argentine	Venezuela	Ecuador	Trinidad,W.I.
1918	2,536,102	1,321,315	190,000	25,000	2,028,068
1919	2,616,000	1,183,000	425,000		1,841,000

STATISTICS FROM THE AMERICAN PETROLEUM INSTITUTE

1919	2,561,000	1,504,300	321,396	2,780,000
1920	2,790,000	1,366,926	500,000	1,628,637

[1]Estimated.
[2]Included in Negritos
[3]Quoted from Richardson, U. S. G. S.
[4]Am. Petrol. Inst.

BULLETIN OF THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS

A PROBABLE BURIED MOUNTAIN RANGE OF EARLY PERMIAN AGE EAST OF THE PRESENT ROCKY MOUNTAINS IN NEW MEXICO AND COLORADO

JOHN L. RICH

Drilling for oil in eastern New Mexico has brought to light evidence of a buried granite mountain range underneath the western margin of the Great Plains, 30 to 60 miles east of the Front Range of the Rockies. The full extent of this range has not yet been revealed and there is uncertainty about some of the connecting links between the known parts, but enough is known to make it possible tentatively to outline its location.

Throughout most of its extent the range is buried under younger sedimentary rocks so that no evidence of its presence is visible at the surface, but at its southern end the covering of sediments has been stripped off and the pre-Cambrian rocks composing its core are exposed. The uncovered portion extends southward along the east side of Estancia valley from a point about 6 miles north of Pedernal Mountain (T. 7 N., R. 12 E.), and has been traced southward by the writer nearly to Corona, a distance of about 50 miles. Beyond this point no attempt to trace it has been made. The width of the pre-Cambrian outcrop in this belt varies up to 12 or 15 miles. The rocks exposed are a typical pre-Cambrian complex of granite, gneiss, schist, and bedded quartzite. The latter forms Pedernal Mountain and the sharp, conical hills around it.

At the time of burial, the surface of the range seems to have been worn down to moderate relief except where especially resistant rocks, like the quartzites of the Pedernal Hills, formed sharp monadnocks rising several hundred feet above the general level. The Pedernal Hills, as they now stand, are the partly exhumed relics of this ancient topography.

The rocks under which this part of the range is buried belong to the Yeso formation of the Manzano group[1] the age

[1]Baker, C. L. The stratigraphy of eastern New Mexico: Am. Jour. Sci., 4th ser., vol. XLIX, pp. 99-126, 1920.

of which is given as early Permian. It is clear from this that the range had been uplifted, stripped down to its pre-Cambrian core, and the latter considerably reduced by erosion previous to its burial in early Permian time. The uplift presumably took place at the close of the Pennsylvanian.

In the latter stages of the burial of the Pedernal Hills, the debris supplied from local sources played a very insignificant part. It is necessary to search carefully within a few feet of the contact to find fragments of the Pedernal quartzite in the rocks under which the hills were buried.

Evidence from well records shows that the buried part of the range is considerably more extensive than the part which is exposed. North of the outcrops in the Pedernal Hills, a number of wells scattered over the area between them and the Santa Fe railroad have found the Pennsylvanian Magdalena limestones entirely cut out and the Abo-Yeso red beds resting directly upon the granite. A well drilled for oil on the Anton Chico Grant, T. 11 N., R. 19 E., also encountered granite directly beneath the Abo-Yeso red beds. It was drilled on a distinct dome which may have been formed by settling over a granite peak.

About 35 miles northwest of this point, in the neighborhood of Bernal, the Magdalena limestone is from 1,000 to over 2,000 feet thick where it is exposed in the present front range of the Rockies. It is also found in the Sandia Mountains, about 30 miles west of the Pedernal Hills. This shows that the site of the present Rockies lies west of the Permian axis of uplift.

In northeastern New Mexico, east of the Rocky Mountain front, there is a deep synclinal basin extending from Las Vegas northward past Raton and Trinidad into Colorado. East of this basin is a broad geanticline from the crest of which the rocks begin their long eastward dip under the Great Plains. This broad structural feature is not very definite at its south end, but it extends roughly from the neighborhood of the Anton Chico well northeastward toward Trementina, thence past Roy, Gladstone, and Folson to the Colorado, where it splits, one branch extending northwest-

ward toward Florence, and the other northeastward toward Lamar[2].

It is suggested that this geanticline probably represents a northward continuation of the buried mountain range which is exposed in the Pedernal Hills and has been encountered in wells north and northeast of them. The evidence on which this suggestion is based is: (1). A well drilled for oil in the valley of Cimarron River, T 31 N., R. 33 E., about 25 miles northeast of Des Moines and a little east of the crest of the geanticline, encountered granite directly beneath the red beds. (2). In southeastern Colorado, between the site of this well and Lamar, Dr. R. D. George, of the University of Colorado informs me that there are 4 or 5 places where granite in the form of small knobs and peaks or of scattered bowlders too large to have been carried far from their source, is exposed at the surface. This granite is coarse and gneissoid, and its appearance suggests that it is a part of the pre-Cambrian complex rather than a later intrusive.

In view of these facts it seems probable that farther south, in Union, Mora, and San Miguel counties, New Mexico, the same structural feature the geanticline east of the Raton Basin is also part of a buried mountain range and will be found to have pre-Cambrian rocks immediately beneath the red beds.

Whether, if such is the case, the range is directly continuous with that of the Pedernal Hills or is *en echelon* with it to the east remains to be determined. It is also uncertain how far east of the crest of the geanticline the Pennsylvanian beds will be found to have been cut out.

In the region between the Pedernal Hills and the Anton Chico well, there is clear evidence of renewed uplift along the buried range during a later part of the Permian period. The evidence consists in the thinning and partial erosion of the San Andreas limestone over the known position of the buried range and the entire absence of the thick salt and gypsum-bearing series of shales and sandstones[3] which

[2]Darton, N. H. U. S. Geol. Survey, Bull. 691-A, 1918, pl. 1.

[3]The Pecos Valley red beds of Baker (loc. cit.) and, probably, the Castile gypsum of other writers.

makes its appearance as a thin wedge above the San Andreas a few miles east of the buried range and thickens rapidly toward the southeast.

In the vicinity of the Anton Chico well, the San Andreas is not over 25 feet thick and is locally marked by contemporaneous brecciation. Several miles farther south along the range where a branch of Pintada Canyon crosses the outcrop, about 15 miles northeast of Encino, the San Andreas is about 80 feet thick and is completely brecciated. Its surface here was exposed to the weather and partly eroded prior to the deposition of the overlying rocks. This is shown by the presence of sink holes in the limestone into which the material forming the beds above had been washed and into which, in places, the lower 5 or 10 feet of the beds above had slumped before the deposition of the beds immediately above them, which show no deformation. Toward the south and east from this locality and San Andreas becomes much thicker and loses its brecciated character.

This later Permian uplift seems also to have affected the geanticline east of Raton, for the log of the well northeast of Des Moines, already referred to, does not show the San Andreas or the salt-gypsum series above it, unless a few thin beds of dolomite may represent them.

If, as seems probable from the evidence at hand, there is a buried granite mountain range of late Pennsylvanian or early Permian age beneath the geanticline which parallels the Raton Basin on the east, this geanticline would be most unpromising territory in which to prospect for oil or gas in rocks older than the Lower Cretaceous because the Magdalena limestones of the Pennsylvanian would be completely cut out and the San Andreas, which is petroliferous and more or less promising where present, would be thin or missing.

It would probably be useless, also, to search for salt deposits in this area, for the salt-bearing series above the San Andreas is presumably absent, and it is not likely that the earlier Permian red beds (Yeso formation) would have been the sea of salt deposition in this anticlinal area.

BULLETIN OF THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS

OIL AND GAS BEARING HORIZONS OF THE ORDOVICIAN SYSTEM IN OHIO

By L. S. Panyity*

INTRODUCTION

Years before Col. Drake drilled the first well for oil and gas at Titusville, Pa., gas seepages had been noted at various points in Ohio. As soon as the importance of natural gas was realized, the citizens of different communities, interpreting the various seepages as surface indications of oil and gas accumulations, organized companies to drill and test the underlying rocks of their vicinity and thus natural gas in the Trenton limestone was discovered at Findlay, Ohio. The first two wells drilled obtained gas in small quantities, but the third well produced over a million cubic feet of gas daily. A small amount of oil made its appearance in the last mentioned well and its presence was looked upon with disfavor by the producing company for it was feared that the oil would interfere with the flow of gas and ruin the well. After the completion of several oil wells the people of Findlay as well as of other cities realized that both oil and gas could be found in commercial quantities in the Trenton, and this humble beginning initiated the development of the great oil and gas fields of northwestern Ohio.

At first only the top portion of the Trenton was tested, and a well without production in the first fifty feet was considered a dry hole. Later deeper pay-horizons were found, and in some instances at least three separate horizons in the Trenton series were found productive.

GEOLOGY

Western Ohio is covered by a mantle of glacial drift and rock outcrops can be found in comparatively few and widely scattered places. Scattered outcrops and quarries permitted the preparation of a geological map of the state, which shows the surface rocks in the western part of Ohio to range from Devonian to Ordovician in age. The oldest rocks are found

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along the axis of the Cincinnati anticline which enters Ohio at Point Pleasant, and with a north to northwesterly trend it crosses the extreme southwestern portion of the state into Indiana. In Randolph county, Indiana, the axis bifurcates, one fork continuing to the northwest, whereas the other branches northeast, enters Ohio and bears toward Lima and Findlay, and thence northward towards Toledo. The production of oil and gas in the Trenton series in Ohio is closely associated with the northeastern bifurcation of the Cincinnati anti-

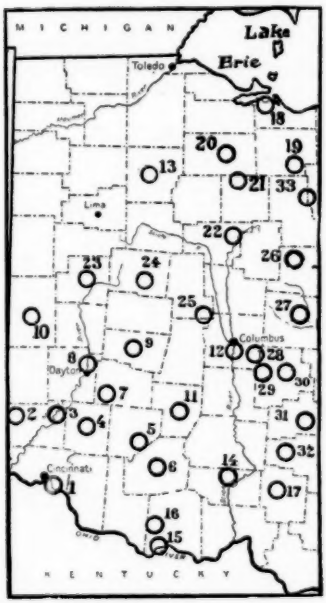

Fig. 1 Sketch map of western Ohio showing location of wells drilled to the St. Peter sandstone.

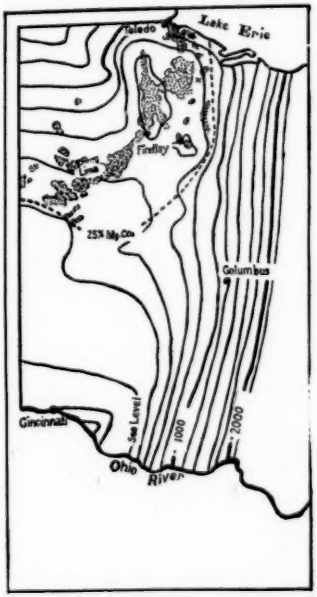

Fig. 2. Sketch map of western Ohio showing oil and gas fields and structure of the St. Peter sandstone.

cline. Owing to the extensive glacial covering, it was impossible to make a structural contour map of the territory until a large amount of drilling had furnished a sufficient number of well records.

The geological studies of Edward Orton Sr. and I. C.

White substantiated the anticlinal theory, as it became evident that production was closely allied to structural deformation. The earlier geologists soon realized that there was another element besides structure which entered into consideration for it was noted that gas accumulations were found in those parts of the Trenton where the chemical analysis showed the magnesium carbonate content to be at least 25 per cent. A dolomitic Trenton limestone was found to be porous enough to contain and yield its contents of oil and gas in commercial quantities, while a pure limestone proved to be too dense to serve as a reservoir rock.

The isobath map accompanying this report (Fig. 1) also shows by means of a broken line the lower limit of the 25 per cent magnesium carbonate content of the Trenton. Thus north and west of this line chemical analyses show the Trenton to be dolomitic up to 25 per cent or more of magnesium carbonate, but to the south and east of the line there is less dolomitization. Although abrupt and irregular changes in composition occur from place to place, nevertheless the position of the line as drawn indicates with sufficient accuracy the limiting magnesium carbonate content of the Trenton. Oil and gas accumulations have been found under where there is favorable structure north and west of the indicated 25 per cent magnesium carbonate line. East and south of the line oil and gas accumulations in the Trenton should not be expected even if the structural conditions are known to be favorable. In the northwestern portion of the state the lack of oil and gas pools is accounted for by the lack of suitable structures, as the Trenton is known to be sufficiently dolomitic. In general the northwestern portion of the state is promising for further development wherever favorable structural conditions can be found.

ST. PETER OR STONES RIVER WELLS

Since 1911 deeper drillings have discovered small oil accumulations at a depth of about 600 to 630 feet below the top of the Trenton, and this rock is generally referred to as the St. Peter sandstone. Prior to 1911 many wells had been drilled to this horizon, but actual production of oil from the

TABLE OF WELLS KNOWN TO HAVE BEEN DRILLED TO ST. PETER SANDSTONE IN OHIO

Numbers refer to map, Fig. 2. Nos. 1-2 after Orton, 13 after Condit, 14 after Bassler

No.	Location	Elev.	Berea	Big Lime	"Clinton"	Trenton	St. Peter	Tot'l Depth	Remarks
1.	Cincinnati	476				300	920	2007	Water at 1650 ft.
2.	Oxford					830	1325	1365	Sulphur water at 1365 ft.
3.	Middletown					630		1060	Water at bottom
4.	Lebanon					662		1300	Water at 1300 ft.
5.	New Vienna					1226		1788	Water at 1785 ft.
6.	Hillsboro					1200		1750	Blue Lick water at 1750 ft.
7.	Spring Valley					860		1500	Water at 1500 ft.
8.	Dayton	825				940	1390	2440	Water at botom.
9.	Springfield	1000				1200		2000	Water at botom.
10.	Grenville					1136	1630	1784	
11.	Washington C. H.	965				1350	1850	1880	
12.	Columbus	900		138- 864		2084	2559	2875	
13.	Findlay			87- 245		1165	1894	2980	Pre-Cambrian at 2770 ft.
14.	Waverly			485- 975		2225	2825		Pre-Cambrian at 3320 ft.
15.	Sprigg Tp., Adams Co.						1365	2006	Ellis Farm.
16	Liberty Tp., Adams Co.					630	1280	1490	McKee Farm.
17.	Oak Hill					3757		4430	E. Martin Farm
18.	Sandusky								20 bbls. oil & water in St. Peter
19.	Grenwich								Drilled 700 ft. below top of Trenton.

TABLE OF WELLS KNOWN TO HAVE BEEN DRILLED TO ST. PETER SANDSTONE IN OHIO—*Continued*

Numbers refer to map, Fig. 2. Nos. 1-2 after Orton, 13 after Condit, 14 after Bassler

No.	Location	Elev.	Berea	Big Lime	"Clinton"	Trenton	S. Peter	Tot'l Depth	Remarks
20.	Tiffin								Seven wells producing from St. Peter.
21.	Lykens Tp., Crawford Co.					1930	2510	2545	Small oil producer
22.	Caledonia	995				2140	2725		Several producers here
23.	Shelby County (Sidney)					1234			Blue Lick water at 1915 ft.
24.	Zanesfield	1150				1470			Drilled thru St. Peter into Blue Lick water.
25.	Plain City	950				1660		2420	2 wells, both in water in this vicinity.
26.	Mt. Vernon		620-650	1435-2272	2391-2395	3645	4515	4576	Show of oil, shot into water.
27.	Homer				2175-2177	3470	4250	4262	Show of oil, water after shot.
28.	Black Lick						3225	3310	No show of oil.
29.	Pickerington (West)	820	At surface	625-1219	1440-1442	2580			Oil at 3225-3235 ft. 5 bbl. well.
30.	Pickerington (East)		262-270	985-1600	1742-1747	3011		3762	Show of oil & water 3667
31.	T. S. Wright, Hocking Co.		740-816	1850-2612	2773-2801	3985		4724	Blue Lick water at 4724 ft.
32.	Jackson Tp., Vinton Co.		743-779	1580-2223	2405-2411	3628	4260	4295	Water in St. Peter.
33.	Ashland County		663-683	1620-2680	2810-2813	4040		5030	No show of oil or water.

St. Peter horizon in Ohio may be considered to date from that time.

Edward Orton Sr. writes as follows:[1] " * * * At the bottom of this (Trenton) series siliceous, magnesian limestone is found which is generally porous and charged with a peculiar salt water known as 'Blue Lick' water. This stratum occupies the place of the Calciferous sandstone . . . (and) . . . this formation is commonly named the St. Peter sandstone. Deep drilling in southern Ohio, however, shows so extended a series of limestone of this same sort that it is hardly

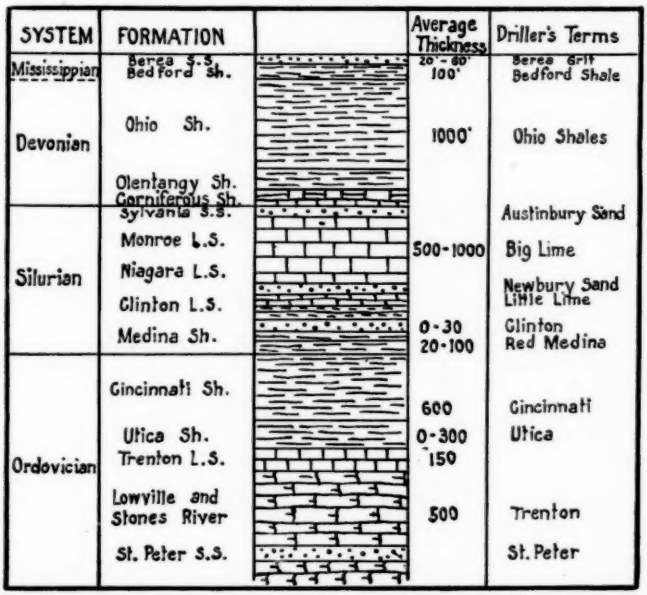

Fig. 3. Columnar section of rocks encountered in western Ohio.

safe to identify any one portion positively as the representative of the sandstone the outcrops of which are six hundred miles or more distant. * * * "

Subsequent studies and tabulations of deep well records in

[1]U. S. Geol. Surv., Eighth Ann. Rept., pt. 2, p. 639, 1889.

Ohio by Bassler[2] and Condit[3] indicates that the horizon described by Orton, is the St. Peter sandstone.

The table of well records shows the various wells which have been drilled deep enough to reach this horizon, and the location of the wells are indicated on the isobath map. Some of the more important and interesting records are given in greater detail.

No. 5 New Vienna.

	Top		Bottom	Thickness
Clinton and Medina	0	—	195	195 ft.
Cincinnati shales	195	—	975	780
Utica Shales	975	—	1,226	251
Top of Trenton at	1,226			
"Birdseye" mark at	1,650			
Salt water at	1,785			

No. 12 Columbus, Elevation 900 A. T.

	Top		Bottom	Thickness
Glacial drift	0	—	123	123 ft.
Black shale (Olentangy shale)	123	—	138	15
Big Lime	138	—	864	726
Medina, Cincinnati & Utica	864	—	2,084	1,220
Trenton	2,559			
St. Peter at	2,559			
Total depth	2,875			

South of Columbus on the Hartman farm a well was drilled which is known to have extended below the St. Peter.

No. 13 Findlay (Modified from D. D. Condit).

	Top		Bottom	Thickness
Glacial drift	0	—	87	87 ft.
Big Lime	87	—	245	158
Medina	245	—	343	98
Cincinnati & Utica shales	343	—	1,165	822
Trenton	1,165	—	1,894	729
St. Peter	1,894	—	2,300	406
Upper Cambrian	2,300	—	2,770	470
Pre-Cambrian at	2,770			
Total depth	2,980			

No. 14 Waverly (Modified from Bassler).

	Top		Bottom	Thickness
Glacial drift	0	—	35	35 ft.
Shales (Ohio shales?)	35	—	485	450
Big Lime	485	—	975	490
Medina	975	—	1,125	150
Cincinnati shales	1,125	—	1,965	840
Utica shales	1,965	—	2,225	260
Trenton	2,225	—	2,825	600
St. Peter	2,825	—	3,000	175
Pre-Cambrian (?) at	3,320 ft.			

[2]The stratigraphy of a deep well at Waverly, Ohio, Am. Jour. Sec., 4th ser., vol. 31, pp. 19-24, 1911.

[3]Deep wells at Findlay, Ohio, Am. Jour. Sec., 4th. ser., vol. 36, pp. 123-136, 1913.

No. 18 Sandusky.

A well drilled in 1920 is said to have produced 20 barrels of oil and salt water daily from the St. Peter. A few years before, a well drilled east of Sandusky, near Huron, found only the "Blue Lick" water in the St. Peter.

No. 20 Tiffin.

A number of wells have been drilled deep enough to reach the St. Peter sandstone in this vicinity, three of which produced oil from that horizon; the best one is claimed to have had an initial production of 500 barrels of oil daily, but the production soon declined to about 25 barrels. The wells were paying propositions but as the percentage of producers was very small, one in about eight (perhaps due to careless locating) it discouraged further drillings. The wells are on a nose on the eastern flank of the Tiffin anticline and about 100 to 200 feet lower structurally than the top of the anticline. The wells made considerable water, and in some instances it was necessary to pump the water for some time before any oil was produced.

No. 21 Lykens Township, Crawford County.

A small producer is found here, which unfortunately was drilled far enough below the oil horizon to reach the underlying water. Scattered well records indicate structure in the top of the Trenton in this vicinity.

No. 22 Caledonia, Marion County.

There are four producing wells in this field, located on a line running approximately north and south, the wells having an initial production of 15 to 745 barrels. Wells drilled east and west found only shows of oil and water. In studying the structure from well records and taking three wells on a line east and west it was found that the center one reached the sand 30 feet higher structurally than the one west of it, and 70 feet higher than the well offsetting it to the east, indicating anticlinal structure.

Log of the discovery well is as follows:

Ulsh No. 1, Elevation 995 A. T.

	Top		Bottom	Thickness
Glacial drift	0	—	130	139 ft.
Big Lime	130	—	920	790
Clinton Shales and lime	920	—	1,020	100
Medina shales	1,020	—	1,100	80
Cincinnati shales	1,100	—	1,850	750
Top of Trenton	2,140			
Oil pay at	2,725			
Water below oil at	2,745			

No. 16. Morris Township, Knox County, (M. J. Popham No. 1)

	Top		Bottom	Thickness
Trenton	3,645	—	4,515	870
Berea	620	—	650	30 ft.
Bedford and Ohio shales	650	—	1,435	785
Big Lime	1,435	—	2,272	837
Little Lime	2,352	—	2,382	30
"Clinton"	2,391	—	2,393	2
Medina shales	2,415	—	3,200	785
Black shales	3,200	—	3,400	200
White shales	3,400	—	3,645	245
St. Peter	4,515			
Total depth	4,576			

Hole full of water at bottom.

No. 29. Pickerington, Ohio.

In the year 1920 a well drilled here reached the St. Peter and found ten feet of "pay-sand" which when pumped produced about eight barrels of oil daily. Two other wells, one north and one east, both reached the same horizon without obtaining any oil in commercial quantities. No doubt further drilling will be carried on here.

Record of discovery well is as follows: (A. .Stemen No. 1)

	Top		Bottom	Thickness
Utica shales	1,850	—	2,140	290
Glacial drift	0	—	96	96 ft.
Bedford and Ohio Shales	96	—	625	529
Big Lime	625	—	1,219	594
Shales and shells	1,219	—	1,440	221
"Clinton"	1,4440	—	1,442	2
Medina shales	1,442	—	1,580	138
Cincinnati & Utica shales	1,580	—	2,580	1,000
Trenton, (limestones to shale)	2,580	—	3,150	570
Shale green	3,150	—	3,225	75
Oil pay at	3,225	—	3,235	10

No. 32. Jackson Township, Vinton, Co., (A. J. Garret, No. 1)

	Top		Bottom	Thickness
Berea	743	—	779	36 ft.
Bedford and Ohio shales	779	—	1,580	801
Big Lime	1,580	—	2,223	643
"Clinton"	2,405	—	2,411	6
Medina shales	2,411	—	2,580	169
Cincinnati & Utica shales	2,580	—	3,628	1,048
Trenton	3,628	—	4,115	487
Dark slate	4,115	—	4,260	145
White sand	4,260	—	4,295	35
Water at	4,278			
Hole full of water at	4,295			

PREDICTIONS

It will be noted that actual production and the best showings of oil are found on the east flank of the Cincinnati anticline, on a rather strong east dip. These oil accumulations are controlled by local structures or reversals which are noticeable when the various well records are compared. Although past performances do not show any extensive discoveries in the St. Peter sandstone, the writer believes that when there is good structure oil may be expected along the steep east flank of the main anticline. The local structures can be mapped out only from well records and discoveries of new pools can be predicted only by a close study of sub-surface geology.

One reason why very large accumulations should not be expected may be the lack of extensive shale beds as a possible source of the oil, overlying the "pay-sand." The older records do not show any shale "breaks" between the Trenton

and the producing horizon. In the eastern wells, where production has been found, a shale bed with a thickness of 25 to 75 feet is recognized by the drillers. If this same condition existed in the western wells no doubt some mention of it would have been made, but no such references are found. As a matter of fact the lack of such a stratum is responsible for the classification in vogue by the drillers, who include the St. Peter in the Trenton, for it is difficult to note any difference in the drilling when passing from the Trenton series into the St. Peter. For this reason the exact division point between the two can be determined accurately in well records only where the shale "break" is in evidence.

It appears to be more than a coincidence that the shale horizon has been noted in that territory where actual production is obtained, and from this the writer would conclude that accumulations can be expected only in a territory where this shale horizon is best developed, which would seem to be coexistant with the strong east dip as indicated in well records. As the overlying formations are known to thicken towards the east, it may be possible that the shale beds also become thicker in that direction.

The oil bearing portion of what is called the St. Peter is a gray siliceous magnesian limestone, containing a great number of small cavities.

The oil found at Caledonia is 38° Baumé and contains hydrogen sulphide. The oil found further south is somewhat lighter both in gravity and color and contains less hydrogen sulphide.

CONCLUSIONS

The available information does not permit the drawing of positive conclusions, but the facts are, that in a few instances paying wells have been found in the St. Peter sandstone at depths within easy reach of the drill in western Ohio. This alone, in the writer's opinion, is sufficient reason to recommend that in those fields where the St. Peter can be reached without great difficulty, it be tested by our larger companies, especially where good structure is present.

In so far as the proper identification of the producing hori-

zon is concerned, the generally understood term of St. Peter has been used in this report. However, it is the belief of the present writer that the oil is obtained from a horizon immediately overlying the St. Peter, and according to this would be classified as the bottom of the Stones River. This conclusion is held for the following reason: The formation which produces the "Blue Lick" water, and which is claimed to be characteristic of the St. Peter, underlies the oil producing zone 15 to 30 feet. Also, the oil is produced from a magnesian limestone, overlying a pure sandstone stratum; this sandstone horizon the writer believes to be the real St. Peter sandstone. The evidence, thus far, is entirely lithological.

DISCUSSION

METHODS OF DETECTING SMALL QUANTITIES OF PETROLEUM

An article by E. Theodore Erickson, Associate Chemist of the U. S. Geological Survey, on "Methods of detecting small quantities of petroleum," published in the July 9 number of the Engineering and Mining Journal, should be welcomed by petroleum geologists. Comprehensive descriptions of simple tests that will detect the presence of oil in fluid, soil, or rock, combined with information regarding the possible confusion of results obtained, are deplorably absent from handbooks on prospecting and oil geology. Hager, in his "Practical oil geology," describes a method of testing, but it is unreliable and much less delicate than the methods described by Erickson. Furthermore, Hager neglects to point out that results which appear to indicate petroleum may actually indicate some other substance.

A significant amount of light gravity oil may be hidden in rocks whose outcrops give no hint of a petroleum content. Frequently this oil content may be detected by the dark color of a fresh surface compared to the weathered surface of the rocks, or it may be betrayed by its odor. However, either of these apparent indications should be confirmed by a positive test. The films on water, so often present in oil-bearing regions, may or may not be formed by oil, and a method of determining their composition is needed. Reliable methods for testing drill cuttings are also required.

Erickson describes two methods of testing—a heat test, performed without reagents, and a solution test with carbon tetrachloride or chloroform. Both methods are sufficiently delicate to reveal the existence of very small amounts of oil. Neither, alone, is conclusive under all conditions, but in many instances positive results may be obtained by applying both tests when a single one is not conclusive. The weakness of the heat test lies in the fact that it gives a positive reaction not only for oil and related bitumens, but also for the pyrobitumens—natural substances of a hydrocarbon nature that will yield true bitumens when subjected to destructive distillation. Thus oil shale, cannels, peat, lignite, and some of the bituminous coals give a reaction under the heat test that is very similar to that given by free petroleum. An experienced experimenter can detect the difference by odor and appearance of the cloud, but erroneous conclusions may easily be reached. The solution test with chloroform or carbon tetrachloride will not dissolve the pyrobitumens, and hence it is particularly suited to supplement the heat test.

The solution test also may yield misleading results. Either chloroform or carbon tetrachloride will dissolve resin, such as is contained in many of the softer coals and in some carbonaceous shales, have been, in many instances, indicative of the presence of resin rather than free oil.

The warning against evaporating chloroform or carbon tetrachloride

in a poorly ventilated room where the vapors may come in contact with a free flame is much needed. Although neither of these liquids is ordinarily explosive, their vapors in contact with a free flame or a heated metal surface will produce such highly poisonous gases as phosgene and chlorine.

K. C. HEALD.

EDITORIAL

COOPERATION

Cooperation is essential for the success of any venture. This Association aspires to be a leader in the world of petroleum geology and the attainment of such success is dependent on the cooperation of all the members.

The most important and essential work of this Association is the annual meeting held in a city accessible to the majority of the Members. Next in importance is the official organ—this Bulletin. An interesting program at the meeting and an interesting Bulletin make a successful year for the Association.

Most of the members believe that the Editor more than any one else is responsible for the program and the Bulletin and that the election of an Editor and the appointment by him of a committee of Assistant Editors relieves the individual members of any obligation to assist with these two enterprises. Although they will admit that they read the Bulletin they do not feel that they are specially called upon to contribute articles, notes or news items. When contributions from them are solicited they offer a variety of excuses to explain why they and their colleagues will do nothing.

During the five years in which this Bulletin has been issued, and not including the present number, 157 articles and notes have been published by 107 Authors. The present membership is over 700. These figures show that a small proportion of the membership does all the work, thus emphasizing the need of wider cooperation. Too often material for good papers is either not worked up for publication, or having been prepared is never submitted. News and items on subjects of current interest to all have to be continually and repeatedly solicited.

The next annual meeting will be held in three months and a number of papers for that meeting can be published in advance in the next two numbers of the Bulletin. All the papers read at the last meeting and now available appear in this or in previous numbers.

The Association requires your cooperation.

GEOLOGICAL NOTES

CALIFORNIA OIL FIELDS

The oil fields of California have recently attracted the attention of some Eastern and Mid-continent operators. The geology and operating conditions of the California fields have been described in detail in various State and Federal publications. This brief review aims merely to present some of the features which present themselves to an operator who is investigating the possibilities of California for the first time.

In order most readily to visualize the oil resources of California, it is well first to gain some impression of the general geological conditions existing within the state. In a general way the most important structural features of the geology of California are governed by the northwest and southeast trend of the shore line, or in other words, the forces which have determined the shore line have also affected the lands along lines which are parallel to it.

The outstanding topographic feature of the state is the inland basin or trough formed by the valleys of Sacramento and San Joaquin rivers. This basin is some 400 miles in length and for a good portion of its distance is nearly 100 miles wide. It will be noted that the courses of these two rivers are almost parallel to the shore line of the Pacific Ocean. To the east of the valleys there lies the Sierra Nevada Mountains, made up largely of granite and similar rocks. It is probable that this range represents the line of greatest activity of the forces which have outlined the geological structure of the state. Between the great inland valley or basin and the coast line lies more or less continuous chain of mountains known as the Coast Range, which at its southern extremity swings eastward and joins the Sierra Nevada Range between Bakersfield and Los Angeles. The core of the Coast Range is made up largely of metamorphic rocks with some granite and volcanics.

The oil bearing rocks of the state are almost all of Tertiary age. They flank the Coast Range, south of San Francisco Bay. North of San Francisco Bay Cretaceous rocks form a large part of the ground surface and rest upon the metamorphic core of the Coast Range. No producing fields have as yet been found in these rocks, although there are a number of oil seepages.

The structure of oil bearing rocks in California is varied. Some of the earliest discovered fields are monoclinal, the oil sands being exposed where they are upturned and eroded. Other fields have monoclinal structure parallel to faults which have raised blocks of older rock, and the oil has seeped out along the fault plane. Some of the more recently discovered fields are in the form of elongated anticlines or domes.

The relative importance of the various fields can best be shown by the following tabulation which gives the daily production and the number of wells in each field:

Field	Daily Average Production	Active Producing Wells
Kern River	20,949	2,190
McKittrick	6,738	324
Midway-Sunset *	139,002	2,561
Lost Hills-Belridge	10,703	607
Coalinga	40,737	1,306
Santa Maria	14,600	429
Ventura-Newhall	5,548	539
Salt Lake	3,820	667
Whittier	2,115	
Fullerton	17,158	
Coyote	20,619	1,032
Montebello	25,368	
Richfield	23,82b	
Huntington Beach	5,615	13
Summerland	145	142
	336,941 bbl.	9,810 wells

*Includes Elk Hills.

The fields which have received the most publicity during the recent months are the Elk Hills, Huntington Beach and Montebello.

The Elk Hills field is in a range where the anticlinal structure is clearly observed and the proximity of the hills to the previously developed Midway field has long indicated that the hills would be productive when drilled. The recent settlement by the Federal Leasing Bill has stimulated development and demonstrated the correctness of geological theories.

The Montebello field, some 10 miles east of Los Angeles, has been developed during the past two or three years. Its discovery was based entirely upon geological work. The anticlinal structure of the hills is clearly discernible but no actual surface indication of oil is to be noted. There was some small escape of gas. There are several productive zones of oil-bearing rock in this field and also several strata of water-bearing rock. The field has been systematically developed so as to avoid damage from water and is an outstanding demonstration of the value of scientific engineering guidance in oil field development.

The Huntington Beach field was discovered about a year and a half ago and illustrates the chances which will hereafter have to be assumed in California wild-cat operations. The geological evidence in the vicinity is limited to the existence of a low range of hills parallel to the shore line and to the mountain range some 30 or 40 miles distance. Similar development in other ranges of hills in the same part of the state have been unsuccessful but in some cases the drilling has not positively demonstrated that oil did not exist. In such prospecting work it is necessary that water shall be excluded from a well and drilling must be carried on so that the formations can be tested for productivenss. This is a somewhat expensive procedure and is not always followed. If, however, such procedure is not followed, an operator is apt to drill a well and then

have no more exact information than if the well had not been drilled.

The fact that new fields have been discovered year after year indicates that there are yet other undiscovered fields in the state and that the production of oil should keep pace with consumption for a considerable number of years in the future.

R. P. McLAUGHLIN.

THE MIRANDO OIL COMPANY WELL, ZAPATA COUNTY, TEXAS

A recent completion of considerable interest is the well of the Mirando Oil Company on section 114 of the Hinant Ranch, in the northeast corner of Zapata County, about 35 miles east-southeast of Laredo. The producing oil sand was found at about 1425 feet which, from three to five feet in, flowed at the rate of 75 to 100 barrels per day (estimated) until the available storage of about 1100 barrels had ben filled. It was then shut in, awaiting the arrival of further storage, and since that time it is reported to be a very small pumper.

The discovery of this oil was probably largely an accident. An earlier well drilled by the same company on the same section, passed through 32 feet of sand at about 700 feet, and 17 feet of sand at approximately the same depth as the present producing sand. Showings were reported in both sands, neither of which were tested. The hole was drilled deeper and abandoned at over 1600 feet. The present well happened to shut down while drilling in the 1,400-foot sand and sufficient oil accumulated through the drilling mud to justify a test.

This is the first oil well in the Tertiary beds of southwest Texas, which bids fair to be of commercial importance (aside from those around recognized salt domes). Gas throughout this area is quite common, and for the past ten years has been the incentive for a wildcat campaign throughout a scope of country about 100 miles square, lying south of San Antonio and east of Laredo. Two commercial gas pools have resulted—the Jennings pool in Zapata county, and the Aguliares pool in Webb County, both now largely depleted. A very small oil pool of slight importance was opened some years ago at Crowther in northeastern McMullen County.

The oil sand in the Mirando well apparently occurs in the top of the Cook Mountain beds. This horizon is also the source of the Crowther oil. The overlying 1,000-1,200 feet belongs to the Yegua formation and the top several hundred feet is probably Fayette or Frio. It is quite likely that the oil sand is to be correlated with the water sand at 1,400 feet, beneath the gas in the Jennings pool, which is situated about 10 miles southwest. The top of the Cook Mountain formation is found in the Aguilares field at around 1,050 feet, and near Rio Grande City at about 2,200 feet. The normal dip throughout northeastern Zapata County is about 50 feet per mile to the east, and the normal strike is a few degrees east of north. The divergent dips through this territory indicate the presence of structure, but satisfactory stratigraphic work is often impos-

sible owing to the lack of suitable key horizons and the heavy accumulation of soil.

The gas in this region comes from lenticular sands in the Yegua clays and no oil of consequence has been reported in connection with it. The Cook Mountain formation has shown heavy oil in several localities but seldom any gas. The gravity of the Mirando oil is said to be 22.9 degrees Baumé, apparently of lubricating grade, paraffin base, with little or no gasoline content. This agrees quite closely with the Crowther crude, where the horizon of the sand is known. The Fayette formation had also shown some heavy black oil, notably at Charco Redondo in Zapata County and in the vicinity of Piedras Pintas in Duval County. It is possible that too little importance has been accorded the Cook Mountain formation as a possible source of oil in southwest Texas, but the outcome in the present well will be of interest in this connection.

W. E. WRATHER.

ANALYSIS OF ZAPATA COUNTY, TEXAS, OIL

The oil in the Mirando Oil Company's well in the northeastern portion of Zapata County is a poor grade because it contains no light oils and because it does not show any lubricating stock. It has a distinct turpentine odor, is dark green in color, has a gravity of 22.2 degrees Baume, and shows a content of 1.1 per cent of B.S. and water.

The following is a distillation test of the first oil produced from the well:

0% to 10%—	Gravity—32.0 degrees Be.
10% to 20%—	Gravity—29.7 degrees Be.
20% to 30%—	Gravity—26.0 degrees Be.
30% to 40%—	Gravity—24.2 degrees Be.
40% to 50%—	Gravity—24.8 degrees Be.
50% to 70%—	Gravity—25.2 degrees Be.

The distillates show no viscosity at all, and are comparable to those in the oil from the upper Woodbine sand at Pine Island, Louisiana.

J. W. BOSTICK.

THE "2-4" SHALLOW OIL AND GAS FIELD, STEPHENS COUNTY, OKLA.

The area that is known as the "2-4" oil and gas field includes parts of sections 13, 14, 23, 24 and 25, of T. 2 S., R. 4 W., and section 19, T. 2 S., R. 3 W. All but the last named are located in the southeastern corner of Stephens County, Oklahoma. This field lies between the Fox field to the southeast and the Velma field to the northwest and takes its name from the township and range in which it is situated.

The topography within the field is rough and irregular, being a part of a prominent topographic "high" which extends in a northwest-southeast direction from a point some distance southeast of the present Fox field through the Velma field and to the northwest. This regional topo-

graphic feature can be seen from considerable distances especially from the south. It is covered with a dense growth of scrub oak. The district is drained by a tributary of Caddo Creek which flows to the southeast.

The rocks exposed are Permian in age and consist of sandstones and shales with one peculiar bed of a mud-lump conglomerate. The exposed series here is similar to that in the Velma field and takes a probable position in the geologic column of the region approximately 150 to 200 feet below the White horse or Duncan sandstone series and almost directly below the sandstone and shale series exposed in the Loco field to the south.

The field lies along a small surface structural "high." The main producing oil and gas sands are found between 200 and 1,200 feet beneath the surface, all within Permian strata. The "Red Beds" of the Permian section are between 1,100 and 1,200 feet thick in this locality, grading downward into non-red sediments. The producing sands are usually gray to white in color, fine to medium grained, slightly calcareous in places and usually fairly loose. Their thicknesses vary from 10 to 40 feet.

The oil produced tests an average of 24 degrees Baumé gravity. The initial productions range from 5 to 75 barrels per day, the individual wells having a gradual decline curve. The field at present has some 180 producing wells and a daily average production of 1,150 barrels.

Drilling in this field has been done almost entirely with the small star machine at an average cost of $3.00 to $3.50 per foot. A string of 8¼ in. casing is set on the top of the producing sand and a 6⅝ in. liner set in the sand. The wells are immediately attached with pumping jacks connected with the power plants. The Magnolia Petroleum Company has a complete gathering system and handles practically all of the oil, usually paying the same price as that of the Healdton crude.

Several deep tests have been drilled in the area in hopes of finding deeper production but without appreciable success.

WILLIS STORM.

THE VELMA OIL AND GAS FIELD, STEPHENS COUNTY, OKLAHOMA

The Velma oil and gas field is situated in the eastern part of Stephens county, Oklahoma and includes parts of Ts. 1 and 2 S. Rs. 4 and 5 W. The principal production comes from the northeastern part of T. 1 S., R. 5 W., and the southeastern part of T. 1 S., R. 5 W. The following sections may be considered as parts of the field: 21, 22, 25, 26, 27, 34, 35 and 36 of T. 1 S., R. 5 W., 1, 2, 3, 10, 11, 12, 14, 15 and 23 of T. 2 S., R. 5 W., and 36 of T. 1 S., R. 5 W.

The town of Loco lies a few miles to the south of the field and the town of Alma a few miles to the east. The town of Velma, from which the field was named, lies in the northeastern extremity of the area. All of the above towns are inland, the nearest railroad being Duncan, Oklahoma, some 25 miles west of the district.

The first well of the field was the Frensley No. 1 of the Texas Company, drilled on geologic advice in section 36, T. 1S., R. 5 W., which found oil in paying quantities July 25, 1917. Since then the field has been growing steadily but it has been only recently that pipe line facilities have been available. The Magnolia Petroleum Company owns and operates the pipe line and gathering system in the field and handles practically all of the oil.

The district lies a few miles west of the Arbuckle Mountains along a series of prominent topographic ridges which are covered with a dense growth of scrub oaks. This series of ridges may be seen from great distances to the south and forms a distinct drainage divide. Within the field the land surface is very rough. Rock exposures are numerous and occur mostly on the sides and tops of the ridges and are usually badly slumped. The roads are as a rule poor, winding in and out through the dense growth of short scrub oaks. The maximum relief is approximately 300 feet, this being the greatest of any area between the Arbuckle and Wichita Mountains. Surface elevations range from 1,000 to 1,300 feet.

All of the rocks exposed are of Permian age usually designated in this region as the "Red Beds" and consist of alternating beds of white sandstones and red shales. The series exposed here is probably lower stratigraphically than that exposed in the vicinity of Loco. The "Red Beds" are approximately 1,000 feet thick in the field and the oil and gas production comes from sands within this series. The following are geologic sections exposed at different points within the area, measured by Mr. W. C. Thompson:

Section in Northeast ¼ of Section 24, T. 2 S. 5 W.

Hard pink and mottled sandstone	6 feet
Loose coarse grained sandstone	5 feet
Purple to gray sandy shale	3 feet
Hard sandy shale	4 feet
Red and gray sandy shale, thin bedded	15 feet

Section south of Grahamite mine, section 6, T. 2 S. R. 4 W.

Fine grained white sandstone	5 feet
Concealed (shale?)	5 feet
Fine grained brown sandstone; breaks into large rectangular blocks	5 feet
Yellow shale	5 feet
Graycross-bedded sandstone, massive	15 feet
Yellow shale	10 feet
Massive white sandstone; iron concretions	10 feet
Shale and brown sandstone	10 feet
Bluish gray sandstone, asphaltic	6 feet
Mottled red sandstone	5 feet
Soft yellowish sandstone	10 feet
Thin bedded gray sandstone	5 feet

The field lies along the southwest flank of what is known as the Velma anticline, a prominent structural feature of the region.

The average daily production of this district is at present approxi-

mately 1,200 barrels from some 216 wells, an average production of 6 barrels per well. The oil is heavy, testing from 24 to 30 degrees Baume. Its price follows that of the Healdton crude. The gas wells range from 2 to 15 million cubic feet although some have been reported as high as 30 million. The amount of gas is somewhat limited and the rock pressure low. It is used mostly as fuel within the field. The oil and gas production comes from sands at the approximate depths below the surface of 400, 600, 700 and 900 feet. A few deeper sands have been found.

Drilling in the district is done almost entirely by Star machines at contract prices averaging $3.00 to $3.50 per foot. Under favorable conditions, a well can be drilled to the 400 or 700 foot level in a week or ten days. The wells are pumped by power stations usually operating 10 or more wells. The shooting of some of the sands encountered has notably increased their production and this practice is increasing rapidly.

WILLIS STORM.

THE HAYNESVILLE POOL

The Haynesville pool, that part of the North Louisiana oil field most recently proved to be commercially productive, is in T. 23 N., R. 8 W., Claiborne parish, just south of the Louisiana-Arkansas state line. It is fifty miles northeast of Shreveport and twelve miles north of the Homer pool.

Haynesville had a population of less than 1,000 before oil was discovered. It had no town water works and no telegraph service. These conditions have changed since March, 1921, and the new Haynesville possesses the usual advantages and discomforts of an oil boom town. It is a station on the Louisiana & Northwest railroad about half way between Gibsland, La., on the V. S. & P. railroad to the south and McNeil, Ark., on the St. L. & S. W. railroad to the north. Haynesville is sixty-four miles by automobile road from Shreveport.

Drilling operations began in the latter part of 1919, during the height of activity at Homer. The Smitherman-Layne-Palmer interests had blocked up a large compact acreage as the result of geological recommendations by Mr. J. Y. Snyder of Shreveport. The Haynesville Oil & Gas Company commenced drilling a well southwest of town, but before it was abandoned as a failure, the Smitherman acreage was turned to the Roxana Petroleum Company of Oklahoma. Mr. F. B. Plummer, assisted by Mr. E. M. Reed, made a detailed geological survey of the structure and two holes were drilled, first in Sec. 14, T. 23 N., R. 8 W., where the pool was later discovered, three miles northwest of town, and then in Sec. 3, T. 23 N., R. 7 W., where no further drilling has been done, five miles northeast of town. Both wells were failures, though both were located on most favorable evidence of structure, and both were apparently drilled to sufficient depth. Altogether six wells were drilled on or near the Haynesville structure within a five-mile radius of Haynesville before

March, 1921, and all were failures though favorable showings of oil and good-looking sands were frequently reported.

After drilling three failures, the Roxana Petroleum Company turned back the acreage with small reservations to Smitherman, Layne, Palmer et al., who began drilling December 4th, 1920, their Taylor No. 2, about five hundred feet south of the original Roxana Petroleum Company's failure, and completed it on March 29th, 1921, flowing 4,000 barrels of pure oil, the discovery well of the new pool. This discovery came one year and four months after commencing the first of six unsuccessful attempts.

Before completion of the discovery well, the Louisiana Oil Refining Corporation acquired seventeen eighties in each of the sections at that time held by Smitherman et al. After the discovery, the Ohio Oil Company bought the major part of the original block amounting to seven thousand acres, or more, together with the Gulf Refining Company, the latter owning a one-quarter undivided interest. The Gilliland Oil Company bought about one thousand two hundred acres. The Roxana retains several hundred acres and the Gulf Refining Company independently owns considerable acreage, but both are largely outside of the original block.

The main part of the developed pool is within a radius of half a mile from the discovery well. Development has been slow and on the whole efficient, because the drilling is controlled by four companies so that syndicates and stock-selling companies as such have had no opportunity to produce artificial boom conditions such as occurred at other pools. The market condition of oil also contributed largely to slow and sane development.

During the period of five months since the first well began to flow four companies have brought in ten wells and made three failures in the original locality. In sections 16 and 27, near the edge of the Smitherman block and one and one half miles west and two miles south, respectively, from the first development, more active and varied drilling has been carried on and six wells have been brought in and one failure made. In the vicinity of the town, two and half miles southeast from the Smitherman gusher, four different drilling interests have made four failures.

Within a radius of four miles of Haynesville, a dozen salt-water wells and dry holes have been drilled and sixteen producers made. Scattered over the pool, more than a dozen wells are being drilled. The principal operators and producers are the Ohio Oil Company, Gilliland Oil Company, Gulf Refining Company, and Louisiana Oil Refining Coorporation. Both the Gilliland Oil Company and the Louisiana Oil Refining Corporation have 6-inch lines and the Standard Oil Company of Louisiana has a 12-inch line in operation.

Production in the Haynesville pool has been remarkably sustained and steady. About 700,000 barrels of pipe line oil has been produced,

and durng June, July and August the average weekly production has been more than 50,000 barrels. About three quarters of the present daily production of more than 9,000 barrels comes from four wells, two belonging to the Ohio Oil Company and two to the Gilliland Oil Company. The Ohio Oil Company's Anna Taylor No. 4 has produced on the average 3,000 barrels of oil daily for three months. The developed pool in the vicinity of the Taylor farms around the discovery well has produced at a conservative estimate, 4,000 barrels an acre for three months. The wells furnishing the largest production show almost no gas, salt-water, or bottom settlings. A sample of the crude shows a gravity of 36.3 Baume and contains 17 per cent gasoline, gravity 58.8 Baume; 23 per cent kerosene, gravity 422.8 Baume; 10 per cent gas oil, gravity 37.2 Baume; 47 per cent fuel oil, gravity 21.9 Baume; loss 3 per cent; B. S. and salt-water, 0.95 per cent.

The topography at Haynesville may be described as an interstream divide between branches of Bayou D'Arbonne on the east which flows into Ouachita River and branches of Bayou Dauchite (Dorcheat) on the west which flow into Red River. The elevation above sea level at Haynesville is 363 feet and about the same in the field. The elevation at Homer (12 miles south) is 255 feet, and over some parts of the Homer pool it is higher than 300 feet. Topographically, then, Haynesville is higher than Homer.

The appearance of the formations at the surface differs very little from that of the beds exposed over a large part of north Louisiana and south Arkansas. The plowed fields and grazing land show a loose yellowish-gray sandy loam in which may be found a few fragments of silicified wood, water-worn fragments and boulders of quartzite. Road cuts show that this surface material, which is in part reworked Eocene, in part Pliocene or Pleistocene, is underlain by alternating reddish-yellow sand and gray clay, which is in turn underlain by chocolate gray sandy clay, all of which contains in places well defined impressions of fossil leaves which probably belong to the Cookfield (Upper Claiborne) formation* of the Eocene.

The vertical section in the Hayesnville pool is made up of about 1,300 feet of Eocene formations including, from the surface downward, carbonaceous sands of the Cookfield, ferruginous sands and marine clays of the St. Maurice, lignitiferous plant-bearing sands and clays of Wilcox and limestone of the Midway. Below these Tertiary deposits, the drill enters the upper Cretaceous, passes through about 700 feet of Arkadelphia clay, and enters the Nacatoch formation at approximately 2,100 feet below the surface. After penetrating three definite chalk beds separated by tough clay and calcareous shale, all of which may

*Similar material collected at Stephens, Ouachita County, Arkansas, has been identified by Prof. E. W. Berry, Paleobotanist, Johns Hopkins University, Baltimore, Maryland, as Cookfield.

represent the Annona chalk, the bit strikes production in the formation generally known in north Louisiana as the Blossom sand, at a depth of 2,850 feet, more or less, or 800 to 850 feet below the top of the Nacatoch sand.

Showings of gas and oil are not uncommonly encountered in the Wilcox lignite and in the Midway line from 1,000 to 1,200 feet but not in large quantity, and very few indications of either are found in the Nacatoch though this is the big producer ("shallow sand") at Homer. All producing wells in the Haynesville pool now developed are in the "Blossom" at a depth of 2,850 feet which is the "Second" or "deep Homer" sand.

The presence of anticlinal structure at Haynesville is indicated by numerous dips in Eocene beds exposed in erosional gullies, ditches and road cuts. One of the clearest reverse dips is shown on the Haynesville-Magnolia road in Arkansas, half a mile north of the state line. The beds are typical of the Upper Claiborne as recognized in the north Louisiana field. They are principally gray clay laminae in rusty-colored sand and contain distinct impressions of fossil leaves. The dip is as much as 3° north-northeast and is exposed 200 feet, or more, along the road. The normal regional dip of beds in this area is from 1° to 4° S. E. On similar evidence the structure was first outlined and the original locations were made. In part of the area the trustworthiness of such structural evidence is justly questionable on account of cross-bedding and similarity of the beds to Pleistocene deposits with which they may be confused. The similarity of Claiborne and more recent deposits is largely the result of reworking near the contact of the two, addition of later gravel, and leaching of ferruginous material.

The structure worked out on this Eocene evidence is a well-defined fold limited by quaquaversal dips, or an oval dome, twice as long as it is wide. The axis extends northeast and southwest with a total length of 13 to 14 miles. The town of Haynesville is on the south flank of the fold, and judging by present development is at the edge of production on this structure. As there is no single bed with peculiar features that may be used as a key horizon, the relief of this Claiborne dome is not easily determined.

In subsurface work on structure in the north Louisiana field, the Nacatoch formation has been generally used for correlation. This is rather closely related to structure on the Blossom, and wherever production occurs below the Nacatoch the top of this sand forms a fairly reliable horizon on which to forecast the depth to production. At Haynesville the interval between the top of the Nacatoch and the top of the Blossom is 800 to 850 feet, or 100 to 150 feet thicker than in the Homer pool.

The Nacatoch structure at Haynesville resembles the Claiborne structure only in a general way. The anticline appears to be rising

and broadening toward the southwest, probably extending the productive pool a number of miles in that direction and suggesting a regional relation between the Haynesville pool and the large gas wells twelve miles to the southwest, east of Cotton Valley.

The Nacatoch is 900 to 1,000 feet relatively lower than in the Homer pool and though at first such a difference only ten miles away seems unfavorable for production at Haynesville, nevertheless the Haynesville pool is on a distinct and separate structure which may prove to be considerably more extensive than the old "wonder pool." From the evidence of wells now drilled, it would appear that the new pool is on the northeast nose of a large, comparatively low anticline reaching southwestward into the next range and township.

In drilling operations, the rotary outfit is used. Surface casing (usually 10-inch) is set at less than 200 feet and 6-inch below 2,750 feet, in the original part of the pool, thus casing off a limestone bed which contains salt water somewhere between 2,700 and 2,750 feet. The well is brought in after setting 4½-inch liner, perforated at the bottom.

Sept. 2, 1921. J. P. D. HULL.

The following press bulletins relative to oil in the Rocky Mountain States have recently been issued by the United States Geological Survey. Copies may be secured from the office of the Survey at Washington on application.

The Ingomar Dome, Montana, by W. T.Thom and C. E. Dobbin.

Oil fields of central Montana, by Frank Reeves.

Possible oil in northeastern Montana, by W. T. Thom, jr. and W. P. Woodring.

Possible new oil field in central Montana, The Alice Dome, a promising anticlinal structure, by W. T. Thom, jr. and C. E. Dobbin.

Devils Basin anticline, Musselshell County, Montana, or Oil fields of central Montana, by Frank Reeves.

Oil fields of central Montana, Cat Creek anticline, by Frank Reeves.

Prospects for oil and gas near Poplar, Montana, by U. S. Geological Survey.

Oil field at Osage, Wyoming, by A. J. Collier.

Mule Creek oil field, Wyoming, By E. T. Hancock.

Oil prospects near Seven Lakes, New Mexico, by Julian D. Sears.

REVIEWS AND NEW PUBLICATIONS

"Field Mapping for the Oil Geologist" by C. A. Warner, field geologist for the Empire Gas & Fuel Company, Bartlesville, Oklahoma. New York. John Wiley & Sons Inc. 145 pp. 1921.

This little book, designed more to serve the beginner in field oil geology than in oil field geology, will be found a useful pocket companion not only by many beginners but also by some who have graduated from that class. A competent scientific or technical critic and also a good literary critic would probably suggest a great many editorial changes in wording and some in content and arrangement but nevertheless in this book a large amount of useful information has been assembled in a form, size and weight that will not burden a hip pocket, much less a specimen bag or kodak case.

The first 83 pages consist of four chapters entitled "Study of Field Conditions, Maps, Their value and Interpretation, Field Mapping and Methods, and Field Mapping Instruments, Their Use and Adjustment." Pages 84 to 116 consist of tables including corrections for curvature and refraction, stadia tables, natural and logarithmic sines and cosines and estimation of depth of well from number of bull wheel revolutions. Pages 116 to 145 are generalized columnar sections for various parts of the country.

The book is especially suited for use in Mid-Continent country, though it contains much that will be usable in the Appalachian, Gulf Coast, Rocky Mountain and California fields.

E. W. SHAW.

AT HOME AND ABROAD

CURRENT NOTES AND PERSONAL ITEMS OF THE PROFESSION

MR. E. B. HOPKINS is in charge of the Geological work of the Andes Corporation in Venezuela, Columbia and Ecuador and will be assisted by Mr. Leon F. Russ.

MR. E. A. TRAGER has gone to Mexico for the Marland interests to remain a year.

MR. W. P. HAYNES recently returned to the United States for a vacation, after a year in Mexico and Central America. MR. C. W. BOUGHTON, who returned with him, will spend the present academic year in graduate study in geology at Harvard.

PROF. J. PERRIN SMITH spent the summer at Eldorado, Arkansas.

MR. E. L. ESTABROOK is now Chief Geologist for the Midwest Refining Co.

MESSRS. F. B. ELY, R. P. WALTERS and LLOYD GIBSON have returned from Mexico.

PROFESSOR A. C. TROWBRIDGE has completed field work for the U. S. Geological Survey Water Supply Paper on the Coastal Plain between the Brazos and Rio Grande rivers, Texas, and is completing the manuscript at the University of Iowa.

DR. L. W. STEPHENSON has been mapping the Cretaceous area west of Uvalde, Texas, for the Bracketville folio of the U. S. Geological Survey.

MR. A. E. FATH has returned to Washington from a trip to Roumania.

MR. DAVID DONAGHUE has resigned from the Gulf Oil Corporation and is engaged in consulting work in Fort Worth.

A valuable report by MR. A. E. FATH, prepared under the joint direction of the U. S. Geological Survey and the State Geological Survey of Kansas, is now in press and will shortly appear as Bulletin 7 of the State Survey publications

MR. D. R. RADCLIFFE, Chief Geologist of the Josey Oil Company, is working at Okmulgee.

MR. RALPH ARNOLD expects to remain in Los Angeles through the coming winter.

MR. C. D. JOHNSON and MR. V. F. MARSTERS have contributed notes

on oil possibilities in Missouri to the Oil and Gas News, of Kansas City, in the issues of July 14th and August 4th, respectively.

MESSRS. T. B. CASE and H. B. THOMPSON have published a paper on "Peg Models—their construction and use," in California Oil Fields, Vol. 6, No. 11, pp. 5-14, May, 1921, issued by the California State Mining Bureau.

MR. K. C. HEALD has been examining the oil fields of Montana and California.

MR. J. D. NORTHRUP has returned to the U. S. Geological Survey after a trip to Peru for the Royal Dutch Shell Co.

MR. WALLACE LEE has gone to Siam for the Siamese Government.

MR. J. O. LEWIS, formerly with the Bureau of Mines, is now with the Smith-Dunn Corporation, of Marietta, Ohio.

MR. A. I. LEVORSEN, of the Greenwood Company, is now located in the Fourth National Bank Building, Wichita, Kansas.

MR. C. L. BAKER is in Brazil.

MR. W. E. HOPPER, of the Brazos River Oil Co., is located at 520½ Spring St., Shreveport, La.

MR. J. ELMER THOMAS is Consulting Geologist for the Shaffer Oil & Ref Co.

MR. J. W. BOSTICK has been in Mexico on a short trip.

MR. ROBERT ANDERSON has not resigned as Chief Geologist for the Whitehall Petroleum Corporation.

MR. W. W. SCOTT, of the U. S. Bureau of Mines, is working on the Haynesville, La., oil field.

MR. STANLEY C. HEROLD has opened an office as Consulting Geologist in the Hotel Phoenix, Buenos Aires, Argentina. He reports that the Government well completed about six months ago produces 5,000 barrels a day partly shut in and has vast potential possibilities. He further reports that the Anglo-Persian Oil Co. is obtaining concessions in Argentina.

MR. ROY S. HAZELTINE is in charge of production of the Sterling Refining Company of Wichita, Kansas. Mr. Hazeltine has purchased an apple orchard in the State of Washington and spent several weeks there this Summer.

MR. HJALMAR ABRAHAMSON is General Manager for the Cliffs Petroleum Company of Denver, Colorado.

MR. J. RUSSELL CRABTREE is engaged in consulting work at 302 South Holyoke Avenue, Wichita, Kansas.

MR. J. Q. MYERS of Fredonia, Kansas, spent the Summer in Montana.

MR. H. B. GOODRICH has moved his office to 214 Mayo Bupilding, Tulsa, Oklahoma.

MR. JAMES P. BOWEN is located at 320 Central National Bank Building, Tulsa, Oklahoma.

MR. E. W. OWEN spent the Summer in Montana for C. R. KEYS.

MR. E. V. WHITWILL is associated with Peters and Wrightsman in Tulsa.

Three wildcat tests, the Owen, Askew and Driver wells, have been completed from a sand at 1900 feet and are good for from 100 to 300 barrels each. These tests are as much as two miles apart and open up what is now known as the Bunger field in Young County, Texas. M. G. CHENEY of Graham, Texas, made the locations and was instrumental in organizing the drilling projects which led to the development. MR. ROY HOLLOMAN is now associated with MR. CHENEY and specializing in geology in Young County and vicinity.

(Errata for Vol. 5, No. 4, the July-August number of the Bulletin of the American Association of Petroleum Geologists, may be found on page 439.)

ERRATA

BULLETIN OF THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS

Vol. 5, No. 4, July-August

Misplacement of galleys in the Symposium on Petroleum Geology has resulted in erroneous page order, as follows:

Page 456 is continued on page 460.

Page 459 is continued on page 463.

Page 462 is continued on page 457.